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GLOBULAR STAR CLUSTERS

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16. Abstract

This book examines different physical characteristics of globular star clusters of our galaxy, obtained from observations performed at different astronomical observatories throughout the world. The first part of the book presents the investigations of different observations and formulas for reducing the observations to a uniform system. The second part of the book gives a catalog of all the globular clusters of all galaxies which are known at the present time, and presents their characteristics in a uniform system with an indication of the sources. The book is designed for specialists in astronomy, students and aspirants studying astronomy.

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A N N O T A T I O N

This book examines different physical characteristics of globular star clusters of our galaxy, obtained from observations performed at different astronomical observatories throughout the world. The first part of the book presents the investigations of different observations and formulas for reducing the observations to a uniform system. The second part of the book gives a catalog of all the globular clusters of all galaxies which are known at the present time, and presents their characteristics in a uniform system with an indication of the sources. The book is designed for specialists in astronomy, students and aspirants studying astronomy.

PREFACE

The basic idea of this book and the catalog of the general characteristics of the globular clusters of our galaxy is very simple. However, some people may find the following ideas to be debatable. / 7*

All of the theories and interpretations of complex phenomena are used to understand nature and the processes taking place within it. The planets, stars, star clusters, galaxies, interstellar and intergalactic medium represent evolving forms of matter whose structure is complex. When developing a theory for these forms of matter or interpreting a certain complex phenomenon, we inevitably must leave out of consideration many details and processes. We cannot examine them, because they are simply not yet discovered or because they are not assumed to be of great significance. Thus, we do not include these characteristics and details in our investigations. This is often related to the assumptions formulated. Unfortunately, the assumptions are frequently not formulated with the requisite accuracy or frankness. In addition, taking information into account which was neglected or omitted may radically change the current interpretation.

This does not negate the heuristic value of theory. On the contrary, the development of any science clearly shows that a good theory, in spite of all its simplifications, leads to outstanding discoveries both in the investigation of nature and in the study of the development of society. However, any good

* Numbers in margin indicate pagination in original foreign text.

theory must be based on facts which are the most reliable for that period of time. A real unity of theory and practice is necessary. It became obvious long ago that globular clusters of our galaxy are representatives of old, relatively autonomous stellar systems. This made them excellent objects for studying stars in late stages of development (in terms of absolute age). When reading a survey published fifteen years ago by H. P. Sawyer-Hogg (1959), one can readily see the striking diversity of the material published at that time on the most general characteristics of globular clusters. About ten years ago, a plan was initiated to reduce the most general characteristics to a uniform system in order to use them with a reliability which was adequate for our era. In spite of that, during these 10 years, numerous new observations were published and a great number of theories were developed. However, the diversity of the material still remains. Throughout this entire period, in Moscow work was carried out to develop a homogeneous system of the basic characteristics of globular clusters. It recently became apparent that /8
it was time to put an end to the continuous processing of data as new information was obtained. A decision was made not to use papers received in Moscow after 31 December 1973. Only in one case was this decision disregarded.

In this paper, an attempt was made to use direct observations. However, in some cases, some of the most important characteristics of globular clusters and the stars populating them could only be obtained by using the equations and relationships following from modern theories. Thus, the unity of theory and practice in this paper was realized as far as possible, although particular emphasis was placed on utilizing observations.

The book consists of two parts.

Part 1 contains a description of the basic characteristics of the globular clusters and the methods of reducing the observations and measurements to a uniform system. Each of the chapters in this part gives brief information on the importance of the examined characteristics of the globular clusters. Analytical tabular values of the quantities used for the reduction are given. In some cases, the original methods and measurements are published. The catalog of the basic characteristics of globular clusters of our galaxy is based on Part 1.

Part 2 contains summary tables of the most general characteristics of the globular clusters. In almost every case we were able to give estimates of the accuracy of the data presented. The tables of Part 2 are preceded by a brief description of them. This description unavoidably obtains certain information given in Part 1. This was done to avoid the necessity of readers using only the catalog to turn to Part 1.

The Preface is given in both Russian and English. Part 1 of the book is only given in Russian. Therefore, at the end of the first section there is a brief explanatory text given in English. That includes a very brief description of the main contents of Part 1.

This book should be regarded as a preliminary attempt. In the near future we hope to not only improve the catalog but also expand it, by adding the globular clusters of the Magellanic clouds, the Andromeda nebula and possibly other stellar systems.

The author would like to express his deep gratitude to many individuals for their assistance in the work. M. P. Popova and N. N. Kireyeva carried out a great amount of computational work on computers, N. P. Kukarkina and N. N. Kireyeva regularly

assisted on different stages of the last period of the work; N. N. Kireyeva took part in the solution of several problems. There was also considerable assistance by V. P. Goranskiy, P. N. Kholopov, A. V. Mironov, N. N. Samus' and Yu. V. Voroshilov who took part in the discussion of several stages of the paper. A number of scientific workers of the Stellar Astronomy and Astrometry Chair of Moscow University and of the Variable Stars Sector of the Astronomical Council of the USSR Academy of Sciences took part in the discussion of some reports which were delivered during the preparation of the book.

G. V. Zaytseva and V. M. Lyutyy carried out a number of photoelectric measurements of globular clusters. A. S. Sharov assisted in the calculations of the interstellar absorption of light. Yu. N. Yefremov and N. N. Samus' assisted in the translation into English. I am deeply indebted to the following persons for sending their books, reports and preprints and communicating new information on globular clusters: H. A. Abt, G. Alcaino, H. C. Arp, L. Detre, R. J. Dickens, O. Eggen, S. M. Faber, W. S. Fitch, C. R. Fourkade, J. Graham, H. H. Guetter, G. H. Herbig, J. E. Hesser, I. R. King, T. D. Kinman, G. E. Kron, K. K. Kwee, J. R. Laborde, T. Lloyd Evans, G. W. Lockwood, W. Lohmann, D. J. MacConnell, G. Mannino, N. U. Mayall, L. Meinunger, W. W. Morgan, P. Th. Oosterhoff, W. Osborn, A. G. D. Phillip, L. Plaut, L. Rosino, R. M. Russev, H. B. Sawyer Hogg, B. Szeidl, C. S. Smith, K. Aa. Strand, G. A. Tammann, A. Terzan, S. L. Th. J. Van Agt, G. B. Van Albada, S. van den Bergh, A. A. Wachmann, A. Wehlau, R. E. White, H. Wilkens, R. F. Wing, F. Zagar.

I would like to thank T. A. Krasyuk and T. D. Nishcheva for their considerable assistance during the preparation of the manuscript for print.

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ERRATA

Errata for NASA TT F-16157
B.V. Kukarkin, "Globular Star Clusters. The General Catalogue of Globular Star Clusters of Our Galaxie"
Scitran, February 1975

page 7	line 1	- use "r" instead of "R"
page 8	line 22	- "background" instead of "backround"
page 15	line 3	- "Schraffierkassette" instead of "Shoraffy plate holder"
page 30	line 11	- "rounded off" instead of "circular"
page 30	line 19	- "photoelectric photometry" instead of "electro-photometry"
page 32	line 18	- "has" instead of "have"
page 34	line 1	- "Lick" instead of "Linsk"
page 37	line 22	- "combined" instead of "global"
page 35	last line	- "Radcliffe" instead of "Radkliffov"
page 39	line 5	- omit comma after Terzan [ie ... of Terzan 5 = IRC-20385 (...]
page 46	line 19	- "photoelectric photometry" instead of "electro-photometry"
page 65	line 26	- "photoelectric ~~photometry~~" instead of "electro-photometry"
page 66	line 12	- "photoelectric ~~photometry~~" instead of "electro-photometry"
page 81	line 2	- "proper motions" instead of "eigen movements"
page 87	line 7	- "proper motions" instead of "eigen movements"
page 87	line 19	- "Kukarkin" instead of "Kukerkin"
page 95	line 7	- "relation" instead of "dependence for"
page 95	line 15	- "relation" instead of "dependence"
page 103	line 12	- "sufficiently reliable" instead of "very unreliable"

INTRODUCTION

The interest in globular clusters has greatly increased in the last 15-20 years. Globular clusters are comparatively uniform aggregates of stars with a mean mass on the order of $10^5 - 10^6$ of the mass of the Sun (there are assumptions regarding larger masses). Globular clusters have a variety of specific characteristics (different integral absolute stellar magnitude, difference in abundance of heavy elements in the atmospheres of stars in a given cluster, as compared with other clusters, different diameters and finer differences). However, all globular clusters are similar, in terms of structure of their spheroids with central symmetry. The Hertzsprung-Russell diagrams (hereafter designated as H-R diagrams) have a common structure, which differs only by the development of a horizontal branch and the inclination of the branch of the giants. This provides a basis for assuming that all of the globular clusters were formed as a result of the same process, which took place at different stages in the development of our galaxy. This may explain their characteristics. /15

The present characteristics of globular clusters are the result of the prolonged influence of evolutionary changes upon the initial conditions which in themselves provided for the dispersion of the basic characteristics (mass, luminosity, luminosity function, etc.).

Globular clusters are the characteristic representatives of the population of such dissimilar stellar systems as the elliptic galaxy M87=NGC 4486= radio source Vir A, the Andromeda nebula (M31 = NGC 224) and both Magellanic clouds. This makes globular clusters suitable objects for extensive space research. Thus, for example, P. J. E. Peebles, R. H. Dicke, 1968 assume that globular clusters could have been formed earlier than the galaxies and are relict objects. Many studies have recently been published devoted to determining the evolution of stars in globular clusters (see, for example, M. Schwarzschild, 1970; I. Iben, 1971), the problem of the helium content (see, for example, A. Sandage, 1969; A. Mironow, 1973), and other problems of contemporary astronomy.

Our problem does not include an historic analysis of the development of opinions on the nature of globular clusters and on the problems of cosmology and cosmogony. There are extensive monographs and summaries devoted to these problems. Without pretending to be complete, we should note the old but classical monograph of H. Shapley, 1930. We should also note the attempt /16 of P. P. Parenago, et. al., 1949 to reduce the observations to a single scale and to formulate a correct concept of the system of globular clusters in our galaxy. We should also note the extensive monograph containing a great deal of information by H. B. Sawyer-Hogg, 1959, and the more contemporary but, unfortunately, already outdated summary of H. Arp, 1965.

In the last 15 years there have been many studies of individual globular clusters of our galaxy, the Magellanic clouds and the Andromeda nebula. Many of these studies will be mentioned and used in the present book.

During the study of the extensive information on globular stellar clusters, carried out in Moscow for more than 10 years, the great diversity of the measurements of the basic characteristics of the globular clusters performed by different authors was discovered. This led us to a general revision of all the accumulated information and to a reduction of all the measurements to a single system.

The present work represents the results of almost 15 years of work. The differing characteristics of the globular star clusters were obtained. They are given in Tables A, B, C, D, E, F located at the end of the book. In the majority of cases, it was possible to not only obtain the characteristics of the globular clusters in a single system, but also to evaluate objectively the errors in a large portion of the values in the tables.

The following text gives all of the necessary information explaining how all the values were obtained in the basic tables of the catalog of the globular clusters of our galaxy.

One of the basic purposes of the study was to obtain universal characteristics of globular clusters directly from observations, so that theoretical considerations, which frequently have a temporal nature, would not influence the results. It was not possible in every case to avoid the influence of contemporary theoretical concepts. Thus, for example, the ratio of the total absorption A to the selective absorption E (B-V) was assumed to equal 3. However, there are opinions regarding the dependence of this value both on the energy distribution in each emitting source, and on the difference of this value in different parts of the galaxy. When the scale of the distances was selected, a significant dispersion was assumed in the absolute values of stars of the RR Lyrae type, based on the contemporary calculations of models of these stars. When determining the value characterizing the content of metals in the atmospheres of stars of different globular clusters, characteristics were used which are related to the chemical composition only based on concepts of contemporary theories. This is obviously unavoidable in any contemporary study. /17

The greatest difficulties are encountered in an examination of the diameters of globular clusters. In this case, preference was given to using direct observations, although theoretical investigations of this problem are very reliable. Unfortunately, preliminary results of the investigations, which were performed by (I. R. King, 1974), were obtained only in January, 1974, and could not have a great influence on our results. However, it was possible to make a comparison with his investigation. H. Wilkens was of great assistance in the problem of the diameters. It was even decided to include his investigations as an independent supplement to this book. However, technical difficulties prevented us from doing this. The investigations of H. Wilkens will be published separately, as a supplement to the collection "Variable Stars".

Exact measurements of the average locations of globular clusters are devoid of a great deal of meaning, due to the extent of these objects and the difficulty in determining the density center. The main purpose of the coordinates of globular clusters is rapid identification on the celestial sphere and a study of their three-dimensional distribution and kinematics. Accuracy up to a tenth of a minute of time in the right ascension and up to one minute of arc in the declination is satisfactory for these purposes.

The coordinates of all the globular clusters, which were known by the time the manuscript was ready to be published (31 December 1973), were carefully verified by means of different lists and maps. In the case of contradictions or discrepancies, independent approximate determinations of coordinates were made. All of the determinations were reduced to the equinox of 1950.0. In some cases adding clusters found to globular clusters was considered unjustified, and these clusters were not included in the catalog (for example, clusters 3 and 8 of the list of A. Terzan, 1971).

In Table A (Page 114) the first column gives the name of the globular cluster used in this book, and the second column gives its name as encountered in the literature, if there is one. For the majority of the clusters, the first column gives their number based on the NGC catalog, and other names are only given for clusters which are not found in this catalog. The clusters are arranged in order of the NGC numbers, so that there can be small inversions in the right ascensions. The third and fourth columns gives the equatorial coordinates for the 1950.0 equinox. For convenience in converting the coordinates to other equinoxes, the fifth and sixth columns give the values of the yearly precession, also for the 1950.0 equinox.

The last two columns of Table A give the galactic coordinates of the globular clusters. They are calculated in a new system used at the present time [coordinates of the northern galactic pole: R.A. = $12^h 49^m$; Decl.=+ 27°4 (1950)].

The coordinates of the globular clusters are not repeated in any of the subsequent tables.

Auxiliary quantities

Table B gives the values of the cosines and sines of the galactic latitudes and longitudes for all the globular clusters of Table A. These quantities may be useful when solving problems related to the investigation of the three-dimensional distribution of globular clusters or in a study of their kinematics. /19
The rectangular galactic coordinates respect to the Sun may be calculated according to the following formulas:

$$x = r \cdot \cos b \cdot \cos l \quad (1)$$
$$y = r \cdot \cos b \cdot \sin l \quad (2)$$
$$z = r \cdot \sin b \quad (3)$$

To calculate the distances of the globular clusters from the center of the galaxy, the following formula may be used

$$R = \sqrt{R_0^2 + r^2 - 2 \cdot r \cdot R_0 \cdot \cos b \quad \cos l} \quad (4)$$

To facilitate all of these calculations, Table B also gives the values of the products of the sines and cosines of the latitudes and longitudes in formulas (1) - (4).

In these formulas R designates the distance of the globular clusters from the Sun; R_0— distance of the Sun from the center of the galaxy; R— distance of the globular clusters from the center of the galaxy.

The last column of Table B gives the values of csc b (in terms of the modulus). These values may be useful when solving problems related to a study of the influence of the interstellar absorption of light in photometric and colorimetric measurements of the globular star clusters. /20

2. INTEGRAL STELLAR MAGNITUDES

Measurements of the integral stellar magnitudes of globular clusters are necessary to determine their absolute values, the luminosity function, and certain other important characteristics.

Attempts to determine the integral magnitudes of the globular clusters were even carried out at the beginning of the century (J. Holetschek, 1904). These determinations were repeated by other astronomers and an attempt was also made to reduce them to a single system (M. E. Nabokov, 1925, 1931). However, random and systematic errors in all these determinations were so great that no attention is now given to them.

Determinations of the integral photographic values of all 93 globular clusters known at the present time were made in the second half of the 20th century (H. Shapley, H. B. Sawyer, 1927, H. Shapley, 1930). These determinations were not very accurate, and the scale of the stellar magnitudes was diverse and nonuniform. However, up to the present integral magnitudes of certain clusters have been determined <u>only</u> in these studies and, in spite of their low accuracy, their use is still unavoidable (see below).

Shortly afterwards, the first attempt at photoelectric photometry of globular clusters was made (J. Stebbins, A. E. Whitford, 1936). This study measured only the integral magnitude of the clusters, defined by three diaphragms of differing diameters. In the majority of cases, even the largest diaphragm was smaller than the diameter of the clusters. Nevertheless, these measurements could be reduced to a single system of stellar magnitudes (see below).

An excellent study using photographic photometry of globular clusters was made by means of a so-called "dot-dash plate-holder". (W. H. Christie, 1940).

Only a little more than 10 years ago studies appeared which made it possible to provide a basis for a system of integral stellar magnitudes of globular clusters (H. L. Johnson, 1959; G. E. Kron, N. U. Mayall, 1960). The last of these two studies carried out tricolor photoelectric photometry of 67 globular clusters with a large group of diaphragms whose dimensions were so large that they encompassed practically all of the stars of even very extended objects. The integral magnitude of the cluster was the asymptote to which the stellar magnitude strived of a given globular cluster, which was measured with larger diaphragms. The stars in the backround can naturally distort the results obtained. Thus, the influence of the background unavoidably increases when a change is made from the galactic pole to the galactic equator. The increasing interstellar absorption of light acts in the opposite direction. /21

In recent years, numerous photoelectric multi-color, and wide-, intermediate-, and narrow-band measurements of globular clusters have been made. Some of them (just as previously, the photographic determinations) were suitable for determining the integral stellar magnitudes.

Before describing the method of reducing all of the determinations of the integral magnitudes of the globular clusters to a single system, we must make some methodical comments. More than 40 years ago it was found (P. P. Parenago, 1930) that the absorption of light in the Earth's atmosphere has a differing influence upon the magnitude of stars and the extent of the objects. Extended objects absorb more strongly than stellar objects. Unfortunately, this effect, which has a simple and unique explanation (with an increase in the atmospheric layer, the light of the weak regions of the extended objects withdraws to the region of noise) has never been studied in photoelectric measurements. However, when comparing photoelectric measurements of globular clusters carried out by different authors, I repeatedly noticed that the greatest differences were encountered in clusters with the lowest altitudes above the horizon. Actually, in this case even a small difference in the latitudes of the observation locations can cause considerable changes in the atmospheric layer. This effect is particularly apparent when comparing the integral magnitudes of very southerly globular clusters measured in the Northern Hemisphere, with the integral magnitudes, measured in the Southern Hemisphere, where the same clusters reach regions close to the zenith on the celestial sphere. Unfortunately, published materials make it impossible to obtain a reliable numerical determination of this effect. Special studies are required. The impossibility of allowing for this effect compelled us to regard it as a certain additional "noise" (in the hope that it would be close to zero when taking the average of several measurements).

The following four series of observations were used to obtain a preliminary system of integral stellar magnitudes of globular clusters:

A. Measurements of integral magnitudes of G. E. Kron, N. U. Mayall, 1960 were made without additional reductions.

B. Measurements of H. L. Johnson, 1959, carried out with a limited number of diaphragms, were reduced to the complete integral magnitudes by measurements of the preceding Series A, corresponding to the same diameters of the diaphragms as the measurements of Johnson. No additional corrections were made. /22

C. Measurements of J. Rousseau, 1964, were expressed graphically, and the "asymptote" was determined for them, just as was done in A.

D. Measurements of J. R. King, 1966, were subjected to the same procedure.

A preliminary mean square error was determined by comparing all four series of observations with each other. It was found to be approximately identical for each series of observations and was close to $\pm 0^{m}.10$. Thus, the simple average of all the investigated series of observations was selected.

The preliminary values thus obtained were used to reduce all other series of observations to system V. Photographic observations were reduced to system B, which was obtained by adding the values of B-V to the preliminary values of V.

Reduction of the measurements of integral stellar magnitudes was performed by two methods a and b (except for special cases):

Method a. If, for the clusters measured in the report being studied, there were already measurements of stellar magnitudes with different diaphragms in the studies A,B,C,D, just mentioned, then the difference between the complete integral magnitude and the magnitude corresponding to the dimension of the diaphragm used was subtracted from the measured magnitude. When there were no measurements in A,B,C,D, clusters were selected with similar diameters and approximately identical differences between the magnitudes in the diaphragms used.

Method b.

For all the globular clusters common to the study investigated and for our preliminary list, based on the studies A,B,C,D, the method of least squares was used to solve a system of equations of the following form

$$V = a + bm_1 + c\lg d \quad (5)$$

Here V—is the integral magnitude of the preliminary list, m_1— measured magnitude with a given diaphragm in the work investigated, and lg d — logarithm of the diameter of the given globular cluster (according to our data reduced to a single system, see page 129).

In determining the final reduced values, the average weighted value was selected (determinations made by the first method had a weight of 2; those made by the second method — a weight of 1).

Previous determinations of the photographic stellar magnitudes usually required more complex methods of reduction to the B scale (see below).

Below we give a description of reducing all the series of observations used by us to our preliminary photometric system in the V and B bands. The observations used by us are arranged in chronological order. /23

1. Determinations of photographic integral magnitudes of Sawyer, H. B. and Shapley, H., 1927 (mSS)

The problem of reducing the photographic stellar magnitudes of Sawyer and Shapley (mSS) is very complex. The scale of the magnitudes (mSS) is not linearly related to the photometric system B. Figure 1 gives a graphic illustration of the dependence of (mSS) and B. It is apparent that we have several "families" of determinations. Seven clusters are brighter than $4^m.5$; ten clusters with magnitudes from $4^m.5$ to $6^m.0$; clusters from $6^m.0$ to $8^m.0$ and clusters from $8^m.0$ to $13^m.0$ can be represented by different linear equations. This is probably due to the fact that the determinations were made using photographs obtained on different equipment and different emulsions. It was found that in each of these sections the magnitude determined depends not only on the true magnitude of the cluster, but also on its diameter, absolute magnitude and color. Since dividing the entire complex of questions measured into four groups is very arbitrary, it was decided to calculate a single reduction equation, omitting two of the brightest clusters. /24

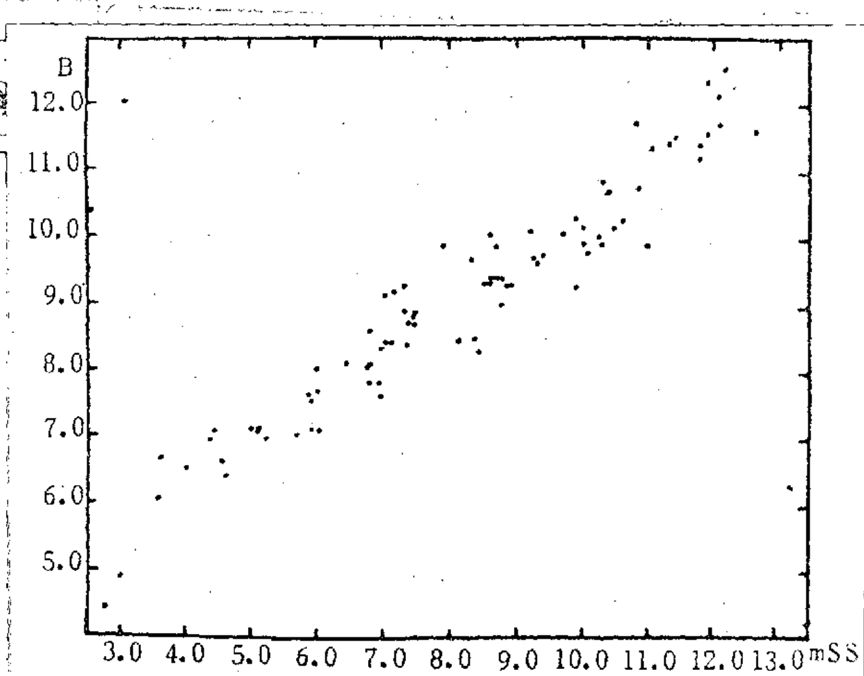

Figure 1. Dependence between integral magnitudes of the globular clusters of Sawyer and Shapley and the magnitudes in system B.

As a result, the following equation was obtained

$$\begin{aligned} B = 8.04 &+ 0.495\ mSS + 0.61\ (B-V) - 1.58\ \lg d + 0.25\ M_B \\ &\pm 0.033 \qquad \pm 0.14 \qquad\quad \pm 0.28 \qquad\quad \pm 0.03 \end{aligned} \tag{6}$$

Here M_B designates the absolute magnitude of the globular clusters in System B.

The mean square error of one determination equals $\pm 0^m\!.37$.

2. Determinations of the photographic integral magnitudes (B. Vorontsov-Volyaminov, 1929) (VV)

The following reduction equation was obtained:

$$\begin{aligned} B = 6.68 &+ 0.46\ VV + 0.73\ (B-V) - 2.76\ \lg d \\ &\pm 0.11 \qquad \pm 0.48 \qquad\quad \pm 0.60 \end{aligned} \tag{7}$$

The mean square error was $\pm 0^m\!.33$.

3. Determinations of photographic integral magnitudes A. N. Vyssotsky, E. T. R. Williams, 1933 (VW)

The following reduction equation was obtained:

$$\begin{aligned} B = 0.80 &+ 0.92\ VW - 0.31\ (B-V) \\ &\pm 0.09 \qquad \pm 0.32 \end{aligned} \tag{8}$$

The mean square error was $\pm 0^m\!.21$.

4. Photoelectric measurements of J. Stebbins, A. E. Whitford, 1936 (StW)

The integral stellar magnitudes were measured with three diaphragms having diameters of 128", 64" and 42". Usually the cluster was measured with one diaphragm as a function of the cluster diameter. There were 52 such clusters. Fourteen clusters were measured with two diaphragms, and only two were measured with three diaphragms.

Both methods described on page 10 were used in the reduction. In the case of the first method, measurements from the studies A,B,C,D were used. For the second method, the following reduction equations were found: /25

$$
\begin{aligned}
V &= 5.60 + \underset{\pm 0.04}{0.73} \cdot StW\,(128'') - \underset{\pm 0.41}{4.28} \cdot \lg d \\
V &= 6.06 + \underset{\pm 0.03}{0.52} \cdot StW\,(64'') - \underset{\pm 0.20}{3.97} \cdot \lg d \\
V &= 6.27 + \underset{\pm 0.06}{0.50} \cdot StW\,(42'') - \underset{\pm 0.59}{3.51} \cdot \lg d
\end{aligned}
\qquad (9)
$$

The integral magnitudes of StW calculated by the two methods were directly compared with our preliminary magnitudes in order to determine the color equation. The following formula was obtained:

$$V = 0.36 + \underset{\pm 0.02}{1.01}\, StW - \underset{\pm 0.09}{0.49}\,(B-V) \qquad (10)$$

The mean square error of the measurement of one cluster was $\pm 0\overset{m}{.}15$.

5. Photographic measurements of W. H. Christie, 1940 (Ch).

The very valuable series of photometric measurements of Christie, performed by means of the "Shoraffy plate holder" were very good with respect to the scale, but not very accurate as compared with our preliminary system of integral magnitudes. The following reduction formula was obtained:

$$B = 0.07 + \underset{\pm 0.02}{1.00}\, Ch - \underset{\pm 0.11}{0.31}\,(B-V) \qquad (11)$$

The mean square error of measuring one cluster was $\pm 0^{m}.25$.

6. Measurements of the photographic integral magnitudes A. Wallenquist and A. Lundby, 1944 (WL)

The integral magnitudes measured by Wallenquist and Lundby may be reduced to System B only by means of two systems of equations (clusters brighter than and weaker than $B = 10^{m}.0$).

$$B = 8.31 + \underset{\pm 0.08}{0.33}\, WL - \underset{\pm 0.58}{0.55}\,(B-V) - \underset{\pm 0.99}{1.21}\,\lg d \qquad (V < 10^{m}.0) \qquad (12)$$

$$B = -0.47 + \underset{\pm 0.20}{1.08}\, WL + \underset{\pm 0.45}{0.41}\,(B-V) - \underset{\pm 0.91}{2.15}\,\lg d \qquad (V > 10^{m}.0) \qquad (13)$$

The mean square error of measuring one cluster was $\pm 0^{m}.26$.

7. Measurements of the integral magnitudes of C. Fehrenbach, 1948 (Fr).

The integral magnitudes measured by Fehrenbach were closer to the photometric system V than B:

$$B = \underset{\pm 0.04}{0.83 + 0.96}\,Fr - \underset{\pm 0.29}{0.59}\,(B-V) \qquad (14)$$

The mean square error of measuring one cluster was $\pm 0^m.21$.

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8. Photoelectric measurements, S. van den Bergh and R. C. Henry, 1962 (vdBH).

The integral stellar magnitudes corresponding to a wavelength close to the V system were obtained with a 28" diaphragm. Both methods described on page 10 were used in the reduction. In the case of the first method, measurements from the studies A,B,C,D were used.

For the second reduction method, the following formula was obtained:

$$V = 9.39 + \underset{\pm 0.07}{0.30}\,vdBH - \underset{\pm 0.33}{5.08}\,\lg d \qquad (15)$$

The mean square error of measuring one cluster was $\pm 0^m.31$.

9. Photoelectric measurements, S. van den Bergh, 1967a, 1968 (vdB67,68).

The integral magnitudes of 46 globular clusters were determined by van den Bergh in 1967, using a 3'.02 diaphragm. Just as in the preceding cases, two methods were used. The following formula was obtained for the second method

$$V = 4.52 + 0.73\ vd\,B67 - 3.11\ \lg d \atop \pm 0.06 \qquad \pm 0.22 \tag{16}$$

The mean square error of measuring one cluster was $\pm 0^m.14$.

In the work of 1968, the integral magnitudes were only given for five globular clusters. They were measured with 60" and 30" diaphrams. The first reduction method was used in the regular way. The derivation of the formula for reduction by the second method was unreliable, due to the small number of clusters. The following equation was obtained formally (graphically)

$$V = 3.05 + 0.71\ vd\,B68 - 3.55\ \lg d \tag{17}$$

However, the errors of the coefficients were so great that the calculated values were used with a double reduction in weight. The mean square error was given an arbitrary value of $\pm 0^m.15$.

10. Photoelectric measurements of J. S. Neff, 1970 (Nf).

Just as in the previous cases, two reduction methods were used. The following formula was obtained

$$V = 4.27 + 0.08\ Nf - 2.67\ \lg d \atop \pm 0.17 \qquad \pm 0.94 \tag{18}$$

The mean square error of measuring one cluster was $\pm 0^m.25$.

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11. Photoelectric measurements of G. V. Zaytseva and V. M. Lyutiy, 1974 (ZL)

The photoelectric measurements were carried out in 1971-1972 in the UBV system with 137" and 68" diaphragms. Reduction to the complete integral magnitude was done by two methods, just as for the other series of observations with diaphragms which did not completely cover the clusters. The following formulas were obtained for the second reduction method:

$$\left.\begin{array}{l} V = 3.50 + \underset{\pm 0.05}{0.78}\, ZL(137) - \underset{\pm 0.30}{2.39}\, \lg d \\ V = 5.54 + \underset{\pm 0.06}{0.83}\, ZL(68) - \underset{\pm 0.35}{3.58}\, \lg d \end{array}\right| \qquad (19)$$

The mean square error of measuring one cluster was $\pm 0\overset{m}{.}12$.

12. Electronographic measurements of G. E. Kron, 1973 (Kr).

In answer to my request, G. Kron kindly gave me the preliminary results of electronographic observations of 14 globular clusters. In addition to the measurement of diameters (see below), Kron also obtained the integral magnitudes of these clusters. His measurements in the V system practically coincide with our preliminary system, and are related to it by the following formula (obtained graphically):

$$V = 0.02 + 0.99\, Kr \qquad (20)$$

The mean square error of measuring one cluster was $\pm 0\overset{m}{.}11$.

13. Photographic measurements of H. Wilkens, 1937 (Wk).

It is particularly interesting to note the first attempt at tricolor measurements of integral stellar magnitudes, which was not completely successful in terms of accuracy but is still interesting in terms of content. The integral magnitudes were measured of 27 globular clusters in three sections of the spectrum b,v,r, close to the B, V and R regions. Their reduction to our system led to the following formulas:

$$\begin{array}{llll} B = 7.75 + 0.39\,(Wk)b & + 0.47\,(B-V) & - 3.09\,\lg d & + 0.27\,z \\ \quad\ \pm 0.08 & \quad \pm 0.36 & \quad \pm 0.57 & \quad \pm 0.27 \end{array} \tag{20a}$$

$$\begin{array}{llll} V = 6.24 + 0.53\,(Wk)g & - 0.40\,(B-V) & - 2.56\,\lg d & - 0.10\,z \\ \quad\ \pm 0.07 & \quad \pm 0.27 & \quad \pm 0.47 & \quad \pm 0.23 \end{array} \tag{20b}$$

$$\begin{array}{lll} V = 7.64 + 0.41\,(Wk)r & - 0.27\,(B-V) & - 2.89\,\lg d \\ \quad\ \pm 0.06 & \quad \pm 0.26 & \quad \pm 0.44 \end{array} \tag{20c}$$

The mean square errors of measuring one cluster were, respectively, ± 0.32, ± 0.25 and ± 0.26.

Each of these formulas was used to calculate the reduced values of the magnitudes according to the data of Wilkens, which were reduced by means of the values (B-V) to the V system. Then the weighted average of these three values was calculated. It was calculated with the weight of 0.4 in a determination of the overall average. /28

Table C gives the weighted average values of V apparent integral magnitudes of all the globular clusters for which measurements or determinations were made. The error of the measurements and the number of measurements were taken into account when establishing the weights. The weight corresponding to the mean square error $\pm 0^m.10$ was used as the unit of weight. The following numbers correspond to the sources, on the basis of which the mean weighted value of V was calculated.

The photographic observations reduced to the B system were reduced to the V system by simple subtraction of the final values of the color equivalents B-V (see the following section), which were derived from the earlier integral stellar magnitudes. The weights of the photographic measurements of the integral stellar magnitudes of the globular clusters were much less than the weights of the photoelectric measurements and were significant only when there was a very small number, or none, of photoelectric measurements, or when they were unreliable.

3. COLOR EQUIVALENTS

In present day photometric systems, color equivalents provide very important information about the physical characteristics of objects and interstellar absorption. In the last 15 years many measurements have been made of globular clusters in the photometric systems U,B,V,I. Therefore, the decision was made to reduce all observations made in these systems, or systems similar to them, to a similar system. In addition, in recent years, many measurements have been made in narrow-band and intermediate-band photometric systems. However, it was impossible to reduce them to uniform systems. In spite of the fact that their information content was greater than the information content of U,B,V,I photometry, the solution was made to only consider the sources in this book (see pages 28 to 31).

A system selected by S. van den Bergh, 1967, was chosen as the preliminary system of globular equivalents B-V and U-B. All of the observations which were used were reduced to it. The system of H. L. Johnson, et al., 1966, was selected with respect to the color equivents V-I. It is related to the system V-I (G. E. Kron and N. U. Mayall, 1960) by the equation

$$\begin{aligned} V-I = {} & 0.245 + 1.203\,(V-I)_{KM} \\ & \pm 0.009 \pm 0.014 \end{aligned} \qquad (21)$$

All the measurements were reduced to the Johnson system.

The reduction of color equivalents to a single system is incomparably simpler than the reduction of integral stellar magnitudes, and is usually reduced to obtaining a linear equation with two terms (zero-point and proportionality coefficient). A description of all the series of observations which we studied is given below.

1. Color system of C2, J. Stebbins and A. E. Whitford, 1936 (StW).

A large amount of measured clusters makes it possible to obtain a reduction formula with great reliability.

$$B-V = \underset{\pm 0.009}{0.883} + \underset{\pm 0.072}{2.748}\, C_2 \qquad (22)$$

The mean square error of the measurement of one cluster is $\pm 0\overset{m}{.}06$.

2. Six-color photometry, J. Stebbins, 1950 (St).

The (B-G) values of Stebbins have the closest relationship with the values of B-V. They are related by the formula

$$B-V = \underset{\pm 0.040}{0.633} + \underset{\pm 0.076}{1.383}\,(B-G) \qquad (23)$$

The mean square error of the measurement of one cluster is $\pm 0\overset{m}{.}03$.

3. Photoelectric color indices of J. Dufay and J. H. Bigay, 1959 (DB). /30

$$B-V = \underset{\pm 0.056}{0.031} + \underset{\pm 0.044}{0.960}\, DB \tag{24}$$

The mean square error of the measurement of one cluster is $\pm 0\overset{m}{.}07$.

4. Photoelectric measurements of H. L. Johnson, 1959 (J).

$$B-V = \underset{\pm 0.030}{1.018}\, J - \underset{\pm 0.031}{0.020} \tag{25}$$

The mean square error of the measurement of one cluster is $\pm 0\overset{m}{.}045$.

5. Photoelectric measurements of G. E. Kron and N. U. Mayall, 1960 (KM).

The measurements were performed in the P-V system, but it is linearly related with the B-V system by the following formula

$$B-V = \underset{\pm 0.012}{0.074} + \underset{\pm 0.013}{1.066}\, KM \tag{26}$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}030$

6. Photoelectric measurements of S. van den Bergh and R. C. Henry, 1962 (vdBH).

The values of C(41-51) were used, which are very closely related to the values of B-V by the equation

$$B-V = \underset{\pm 0.048}{0.039} + \underset{\pm 0.060}{1.027}\, vdBH \tag{27}$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}049$.

7. Photoelectric measurements of J. Rousseau, 1964 (Rou).

$$\begin{aligned} B-V = \; & 0.006 + 0.999\,(\mathrm{Rou}) \\ & \pm 0.024 \pm 0.023 \end{aligned} \tag{28}$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}036$.

8. Photoelectric measurements of I. R. King, 1966b (Kn).

Only measurements which were made with the three largest diaphragms were used in calculating the reduction. Since nine clusters in all were measured with a very small dispersion of the B-V values, it was decided not to calculate equations of the regular type, but to limit ourselves to only the average difference between the measurements of King and the system of van den Bergh

$$B-V = \mathrm{Kn} + 0.02 \tag{29}$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}021$.

9. Photoelectric measurements of S. van den Bergh, 1967a, 1968 (vd3). /31

$$\begin{aligned} B-V = \; & 0.018 + 0.981\,\mathrm{vdB} \\ & \pm 0.013 \pm 0.015 \end{aligned} \tag{30}$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}019$.

10. Intermediate band photometry, J. S. Neff, 1970 (Nf).

The half-sum of two intermediate band color equivalents $0.5(x_1 + x_2) = Nf$ was found to have the closest relationship with the B-V values. The following equation was obtained

$$B-V = \underset{\pm 0.019}{0.316} + \underset{\pm 0.036}{1.146}\, Nf \qquad (31)$$

The mean square error of measuring one cluster is $\pm 0^m.023$.

11. Photoelectric measurements of H. H. Guetter, 1973 (Gt).

The numerous measurements of Guetter, which were kindly put at our disposal, were performed in a system of six-color photometry. The B-G values were found to have the closest relationship with the B-V values. They were related by the equation

$$B-V = \underset{\pm 0.008}{0.587} + \underset{\pm 0.029}{1.361}\,(B-G) \qquad (32)$$

The mean square error of measuring one cluster is $\pm 0^m.045$.

12. The intermediate band photometry of S. M. Faber, 1973 (Fab).

The intermediate band color equivalents (45-55) were found to have the closest relationship with the B-V values. The following equation was obtained:

$$B-V = \underset{\pm 0.026}{0.183} + \underset{\pm 0.050}{1.139}\,(45-55) \qquad (33)$$

The mean square error of measuring one cluster is $\pm 0^m.022$.

13. The photoelectric measurements of G. V. Zaytseva and V. M. Lyutiy, 1974 (ZL).

The measurements were used before they were published.

$$\begin{aligned} B-V &= 0.038 + 0.968\,(ZL) \\ &\pm 0.024 \pm 0.023 \end{aligned} \qquad (34)$$

The mean square error of measuring one cluster is $\pm 0^m.046$.

/32

There were fewer measurements of the very important color equivalents U-B and they were less accurate than the B-V measurements or the equivalents close to them. Nevertheless, their measurement was particularly important, because, since they encompass the region of the Balmer discontinuity and the ultraviolet emission behind the discontinuity, the U-B values provide additional information about the chemical composition of the stellar atmospheres.

Information is also given about the series of measurements of the U-B values or the equivalents close to them, which we employed.

1. Photoelectric measurements of H. L. Johnson, 1959 (J).

$$\begin{aligned} U-B &= 0.013 + 0.997\,J \\ &\pm 0.008 \pm 0.018 \end{aligned} \qquad (35)$$

The mean square error of measuring one cluster is $\pm 0^m.024$.

2. Photoelectric measurements of J. Rousseau, 1964 (Rou).

$$\begin{array}{l} U-B = 1.114\,\mathrm{Rou} - 0.015 \\ \quad\quad \pm 0.062 \quad\quad \pm 0.016 \end{array} \qquad (36)$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}026$.

3. Photoelectric measurements of S. van den Bergh, 1967a, 1968 (vdB).

$$\begin{array}{l} U-B = 0.011 + 0.942\,\mathrm{vdB} \\ \quad\quad \pm 0.007 \pm 0.019 \end{array} \qquad (37)$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}025$.

4. Intermediate band five-color photometry of R. D. McClure and S. van den Bergh, 1968 (vdBC).

The sum of all four color equivalents C(42-45) + C (41-42) + C (38-41) + C (35-38) = vdBC, had the closest relationship with the values of U-B. The following equation was obtained

$$\begin{array}{l} U-B = 0.825\,\mathrm{vdBC} - 0.839 \\ \quad\quad \pm 0.019 \quad\quad \pm 0.020 \end{array} \qquad (38)$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}036$.

5. Intermediate band photometry of J. S. Neff, 1970 (Nf).

The sum of two intermediate band color equivalents $(x'_2 + x'_3) = \mathrm{Nf}$, had the closest relationship with U-B values. The following equation was obtained:

$$\begin{array}{l} U-B = 0.744\,Nf - 0.079 \\ \quad\quad \pm 0.034 \quad\quad \pm 0.019 \end{array} \qquad (39)$$

The mean square error of measuring one cluster is $\pm 0\overset{m}{.}032$.

6. Photoelectric measurements of H. H. Guetter, 1973 (Gt). /33

The measurements were performed in a six-color photometric system. The combination of the $\frac{1}{3}[(U-V)+2(U-B)]=Gt$, colors was found to have the closest relationship with the U-B values. They were related by the equation:

$$\begin{aligned} U-B = \; & 0.149 + 0.831\,Gt \\ & \pm 0.009 \pm 0.030 \end{aligned} \qquad (40)$$

The mean square error of measuring one cluster is $\pm 0^m.051$.

7. Intermediate band photometry of S. M. Faber, 1973 (Fab).

The following combination of intermediate band measurements of S. M. Faber was found to have the closest relationship with the U-B values: $Fab = \frac{1}{3}[(35-45)+2(38-45)]$. Both values are related by the equation

$$\begin{aligned} U-B = \; & 0.812\,Fab - 0.678 \\ & \pm 0.034 \quad \pm 0.036 \end{aligned} \qquad (41)$$

The mean square error of measuring one cluster is $\pm 0^m.021$.

8. Photoelectric measurements of G. V. Zaytsova and V. M. Lyatiy, 1974 (ZL)

The measurements were used before they were published.

$$\begin{aligned} U-B = \; & 0.013 + 0.941\,ZL \\ & \pm 0.011 \pm 0.027 \end{aligned} \qquad (42)$$

The mean square error of measuring one cluster is $\pm 0^m.029$.

Unfortunately, there are very few observations of the globular clusters in the near infrared region; however, they are very diverse with respect to the bands which were selected by the observers. A comparison of individual series of observations showed that they may be readily reduced, without systematic deviations, to the V-I system which we selected (H. L. Johnson, et al., 1966).

Information is also given about the series of measurements of V-I which we employed or the equivalents similar to this system.

1. Six-color measurements, J. Stebbins, 1950 (St).

The G-I difference of Stebbins was found to have the closest relationship with the V-I values. The following equation was obtained

$$\begin{array}{l} V-I = 0.915 + 0.917\,St \\ \quad\quad\;\; \pm 0.012 \pm 0.008 \end{array} \tag{43}$$

The mean square error of measuring one cluster is $\pm 0^{m}.022$.

2. Photoelectric measurements of G. E. Kron and N. U. Mayall, 1960 (KM). / 34

$$\begin{array}{l} V-I = 0.245 + 1.203\,KM \\ \quad\quad\;\; \pm 0.009 \pm 0.014 \end{array} \tag{44}$$

The mean square error of measuring one cluster is $\pm 0^{m}.042$.

3. Six-color measurements of H. H. Guetter, 1973 (Gt).

The G-I difference of Guetter was found to have the closest relationship with the V-I values. They are related with each other by the following formula:

$$\begin{array}{l} V-I = 0.960 + 0.846\,Gt \\ \quad\quad\;\; \pm 0.018 \pm 0.019 \end{array} \tag{45}$$

The mean square error of measuring one cluster is $+0^m_.070$.

4. Intermediate band photometry of S. M. Faber, 1973 (Fab)

The difference obtained by Faber (74-55) for 10 clusters was found to have the closest relationship with the V-I value. The formula relating these values was obtained graphically

$$V-I = 1.33\ \mathrm{Fab} - 0.155 \quad (46)$$

The mean square error of measuring one cluster is $\pm 0^m_.022$.

Table C (Page 120-125) gives the average weighted values of the integral stellar magnitudes in the V system of the color equivalents B-V, U-B, V-I. A unit of weight corresponds to the mean square error $\pm 0^m_.10$. The columns behind each of the four values give the sources designated by numbers corresponding to the studies which were used in calculating the weighted average. A list of them is given after the table, and the complete source is given in a list of sources used at the end of the book.

Narrow band, intermediate band photometry and spectrophotometry of globular clusters

The integral spectra of globular clusters represent the total effect of superimposing the spectra of all the stars in a cluster. It is apparent that the integral spectrum is primarily determined by those stars in the cluster which make the greatest contribution to the total emission of the spectral regions of interest to the researcher. Therefore, the gradients of the spectra themselves as well as the spectrophotometric measurements, and the intermediate- and narrow-band photometry, cannot be unequivocal functions of temperature, chemical composition, or any other characteristic of the cluster emission. Nevertheless, such studies are important, since they make it possible to make a tentative judgment about the physical characteristics of globular clusters.

A list of published studies in this discipline and their brief characteristics is given below. /35

1. S. van den Bergh and R. C. Henry, Publications of David Dunlap Observatory, Vol. 2, 1962, pp. 281-313.

The relative intensities for several circular values of wavelengths are given for 21 globular clusters, obtained by scanning the spectra. They are used to derive auxiliary values, correlated with temperature, the content of heavy elements, etc. We partially used these measurements already, and will use them below.

2. R. D. McClure and S. van den Bergh, Astronomical Journal, Vol. 73, 1968, pp. 313-337.

Intermediate-band electrophotometry of 67 globular clusters, as a result of which the following color equivalents were derived: C(42-45), C(41-42), C(38-41) and C(35-38). They may be used to derive the auxiliary values which are correlated with temperature and the content of heavy elements. The measurements were already used previously to obtain the U-B values and will be used below.

3. H. L. Johnson and D. H. McNamara, Publications of Astronomical Society Pacific, Vol. 81, 1969, p. 485.

Narrow band photometry of 15 globular clusters. The values b-y, m_1, c_1 and β were measured. The measurements will be used later to determine the content of metals and the spectral class.

4. J. S. Neff, Montly Notices, Royal Astronomical Society, Vol. 149, 1970, pp. 45-50.

The intermediate-band photoelectric measurements in four spectral regions. The x_1, x_2, and x_3 values obtained make it possible to determine the temperature, spectral, and regular color equivalents. The measurements were already used and will be used below in the text. In all, nine globular clusters were measured.

5. W. H. Osborn, Position of Globular Cluster Stars in the Physical H-R Diagram, Thesis, 1971.

The intermediate-band measurements of individual stars in the globular clusters M3, M5, M10, M13 and M92, obtained by determining temperature, content of metals, and acceleration of gravity on the surface. They will be used below in the text.

6. S. M. Faber, Astrophysical Journal, Vol. 179, 1973, pp. 731 - 754.

Ten-color, intermediate-band electrophotometry of ten globular clusters in the 3500 - 7400 Å wavelength region. Many derivative values were obtained from them, making it possible to determine several characteristics. The measurements were used to obtain the color equivalents, and will be used below in the text.

In addition, individual determinations, which were made concurrently with other studies, of different characteristics of individual globular clusters were published. They will be used later in the text with the corresponding biographical references. /36

The recent discovery of the excess infrared emission in the spectrum of the M15 cluster (McGregor, et al, 1973) at a wavelength of 10.2 μ, is extremely interesting and very promising. The nature of this phenomenon is still unknown; however, it is apparent that we must search for similar phenomena in the central regions of very massive globular clusters of great luminosity, strong concentration, and large dimensions of the nuclei (for example, 47 Tuc, ω Cen, M3, NGC 6093, M92, NGC 6541, M2).

The identification of the globular clusters M92 and M15 with X- sources of 3U 1736 + 43 and 3U2131 + 11 is very interesting, but requires verification. If the identification is confirmed, further studies of X-ray emission of the globular clusters will be very desirable.

A. G. Davis, Philip, 1973 have carried out numerous narrow-band photoelectric observations of stars in certain globular clusters, primarily with respect to the hot stars of the horizontal branches. The study has been very informative.

Everything related to spectral and photometric studies of global characteristics of globular clusters awaits a more extensive theoretical interpretation. The accumulated knowledge about the functions of luminosity and the color of several globular clusters makes it possible to formulate valid models and to compare the characteristics of these models with the observed characteristics of the clusters. This problem will arise in subsequent chapters of the book, but we shall not return to it each time.

4. SPECTRAL CLASSES

The determination of the integral spectral classes of globular clusters is of great importance, if only for the simple reason that the criteria of spectral classification do not depend on interstellar absorption, in contrast to almost all other photometric measurements. It is true that the chemical composition of the stars in globular clusters is closely related to the criteria of spectral classification. This leads to difficulties and contradictions in spectral classification.

If we do not take into account the pioneering attempt to determine spectral classes of globular clusters of the veteran of spectral stellar classification, A. J. Cannon, (1929), we must consider the first contemporary study to be that of N. U. Mayall, 1946.

Like many of our predecessors, when selecting a system of spectral classification we employed the determinations of W. W. Morgan, 1956 and T. D. Kinman, 1959b. Both of these series of observations practically coincide and are based on the CH/Hγ ratio. We did not take into account the systematic difference between the determinations of one and the same clusters by these authors which amounted to less than one tenth of a spectral subclass. All of the remaining determinations of the spectral classes are reduced to this system. Below we give a list of all the spectral series of observations used and the reduction formulas or tables.

1,2. Spectral classification of N. U. Mayall, 1946.

The study of Mayall gives two series of spectral classes of criteria used at the Mt. Wilson Observatory and measured in the old system. The first series corresponds to spectrograms obtained with a spectrograph on a 36" refractor, of the Linsk Observatory. These spectral classes are related with the CH/Hγ system which we selected by the following equation

$$Sp = F4.46 + 0.41\,(M36'' - F0) \tag{47}$$

where the value (M36" - F0.0) designates the difference between the spectral class of Mayall and F0.0 expressed in tenths of a spectral class.

The second series of Mayall corresponds to spectrograms obtained on the Crossley reflector. These spectral classes do not have a linear relationship with the system we selected, and the dependence is tabulated. The first symbol corresponds to the spectral class according to Mayall (MC), and the second — to the spectral class in our system. /38

MC	CH/Hγ	MC	CH/Hγ	MC	CH/Hγ	MC	CH/Hγ
A5	F2.0	F0	F3.3	F5	F5.3	G0	F8.0
A6	F2.3	F1	F3.7	F6	F5.8	G1	F8.6
A7	F2.5	F2	F4.0	F7	F6.3	G2	F9.5 or G6.0
A8	F2.8	F3	F4.5	F8	F6.8	G3	G0.2 or G4.6
A9	F3.0	F4	F4.9	F9	F7.4	G4	G1.8

As may be seen, for spectral classes later than G1, this dependence is ambiguous. The value which is in best agreement with other determinations is usually selected.

3,4,5. Spectral classification of Morgan, 1956, Kinman, 1959 b.

As was pointed out above, the spectral classification of Morgan and Kinman, based on the Ch/Hγ ratio, was used by the authors as the system. Both series of determinations of Morgan, which he carried out both from spectrograms obtained by Mayall on the Crossley reflector and from specially obtained spectrograms on the 82" reflector spectrograph of the MacDonald Observatory, are based on the MK standards. Measurements of Kinman, obtained from spectrograms on the 74" reflector of the Radkliffov Observatory in South Africa are based on the same system.

6. Spectral classification of S. Van den Bergh, 1969.

Studying the photometric and spectroscopic characteristics of globular clusters in the Andromeda nebula, Van den Bergh determined the spectral classes of 42 globular clusters in our galaxy. He applied the MK standards to four spectral regions: the lines of H and K Ca II, λ4226 Ca I, the G band and λ4325 Fe I. Fortunately, just like many other characteristics of globular clusters based on spectral or photometric characteristics, these measurements of Van den Bergh are related both with temperature and with the content of the heavy elements. In other cases, they may be used both for spectral classification and for determining the content of metals. The average values of the four determinations of Van den Bergh, which he designated by the symbol L, had the best agreement with the system of spectral classes which we selected. These values do not have a linear relationship with our system and are tabulated (see the table).

L	CH/Hγ	L	CH/Hγ	L	CH/Hγ	L	CH/Hγ
A9	F2.0	F3	F5.2	F7	F8.9	G1	G4.0
F0	F2.7	F4	F6.3	F8	G0.0	G2	G5.8
F1	F3.5	F5	F7.0	F9	G1.2	G3	G7.5
F2	F4.3	F6	F8.0	G0	G2.5		

7. Spectral classification of P. J. Andrews and T. Lloyd Evans, 1973 (ALE) /39

Using somewhat different criteria than those of Kinman, the authors determined the spectral classes of 17 globular clusters with the spectrograph in the prime focus of the 74" reflector of the Radkliffov Observatory. A comparison of the spectral classes which they determined using the G band with our spectral classes led to the following linear equation

$$Sp = 1.014\,(ALE - F0.0) - 0.35 \tag{48}$$

where the value (ALE-F0.0) designates the difference between the spectral class of the author, and F0.0 expressed in tenths of a complete spectral class.

In contrast to the integral stellar magnitudes and the color equivalents, whose numerical values always make it possible to determine their accuracy, it is more difficult to determine the accuracy of establishing spectral classes. Nevertheless, a comparison of the preliminary (before introducing the weights) average values with the values of individual series of determinations makes it possible to determine the relative accuracy. It was found that the measurements of spectral classes of Morgan, Kinman, Andrews and Lloyd Evans were the most accurate. They used a weight of 3, using as the unit weight the quantity corresponding to the mean square error in one tenth of the complete spectral class. In the case of possible uncertainty, these weights were reduced the corresponding amount. All the remaining direct determinations of spectral classes were given the weight of 1.

In addition to direct determinations of spectral classes, indirect determinations were made, based on photometric measurements.

1. Measurements of intensity of G-bands of S.C.B. Cascoigne and J. A. Koehler, 1963.

The quantities γ show the correct correlation with spectral classes. Corrected for interstellar absorption, these quantities are related with the spectral classes by the following equation found graphically

$$Sp = 40.2\,(\gamma - 3) - 6.9 \tag{49}$$

The deviations from the reliably determined spectral classes of several clusters were used to determine the weight, which was found to be close to 0.1.

2. Intermediate band photometry of R. D. McClure and S. van den Bergh, 1968.

The narrow band measurements of C(42-45), corrected for interstellar reddening, were found to have a definite dependence on spectral classes. The following equation was obtained graphi- /40
cally where C*(42-45) designates the value corrected for absorption

$$Sp = 54.0\,C^*(42 - 45) - 15.1 \tag{50}$$

The deviations from the assumed values lead to a weight of 0.5.

3. Intermediate band photometry of S. M. Faber, 1973.

The value $(G)_0$ has a clear dependence on spectral class. This value was changed somewhat due to the fact that our values for interstellar reddening did not agree with the values used by Faber. The following formula was obtained graphically

$$Sp = 48.65\,(G)_0 - 5.6 \tag{51}$$

A weight of 1 was determined from the deviations of the calculated spectra from the assumed spectra. At the end of the book, the tables of the final values of the unified global characteristics of globular clusters give all of the values of spectral classes - derived only by means of indirect (photometric) methods - in parentheses, although they may sometimes be more accurate than the poor direct determinations (see table D).

Unfortunately, the integral spectral classes of globular clusters are closely related to the content of metals and it is difficult to find methods of separating them reliably. Therefore in several cases, particularly when there were contradictions in individual determinations, a mutual correction of reliability was made using Equation (71), on the basis of independent determinations of [m/H] and the spectral classes.

The final values of the spectral classes are given in Table D. The unit of weight corresponds to one tenth of a complete spectral class. However, in contrast to the weights of other values in the catalog, the weights of the spectral classes are arbitrary to a certain extent.

5. TRUE COLOR EQUIVALENTS OF GLOBULAR CLUSTERS IN THE U, B, V, I PHOTOMETRIC SYSTEM AND COLOR EXCESS /41

As was already noted in the Introduction, many parts of this book are closely related to each other; when a certain problem is discussed it is impossible to avoid referring to subsequent sections. Thus, for example, when deriving the integral stellar magnitudes, it is necessary to know the values of the color equivalents. Studying the numerical relationships between the narrow-band or intermediate-band photometric measurements and spectral classes, it is necessary to know the color excess, etc.

To a significant extent, this statement pertains to this portion of the book. It is impossible to speak of true colors of globular clusters, without knowing the color excesses, whose determination will only be made in a subsequent chapter.

Globular clusters are very favorable objects for studying the interstellar absorption of light. They are encountered at almost all latitudes, but have a strong concentration toward the center of our galaxy. Their luminosity is so great and their external appearance is so characteristic that it is easy to identify them at large distances from the Sun. The determination of such absorbed objects, as the globular cluster of Terzan, 5=IRC-20385 (A. Terzan, 1968, 1971) makes it possible to establish the value of the overall and selective absorption of light at great distances which would be difficult to reach by means of other objects of the stellar medium in the optical frequency range. The relative abundance of globular clusters in the center of our galaxy is particularly important, since, for example, we still do nc know with reliable accuracy the distance up to the center of the galaxy.

Use of the observed values of color equivalents for determining the color excesses connected with the overall absorption by simple relationships requires a knowledge of the true (free from selective absorption) values of these equivalents. In the present chapter of the book, a method is described for obtaining the true values of the color equivalents $(B-V)_0$, $(U-B)_0$ and $(V-I)_0$. This was done by certain approximations.

The color excesses E (B-V) were determined by different methods which were not related to the measurements of the color equivalents of the clusters themselves. Color excesses were used which were calculated (according to the law of latitude cosecant) for globular clusters with galactic latitudes outside of the ±30° band. The method of Paron-Sharov (A. S. Sharov, 1963) was followed. These methods could not give precise values of the color excesses of each cluster, but they were suitable for a general solution of the problem with a sufficient number of clusters. In some cases, estimates of the color excesses of stars in the field in the vicinity of individual clusters were used. Finally, the color excesses were determined by comparing different points and the sequences of the most reliable diagrams of the color-luminosity with diagrams of the clusters in which the color excesses were very small and known. It is true that we always must recall that these determinations have small but unavoidable errors related to the axiomatics lying at the basis of the selection and calibration of absolute values of the points selected and the sequences.

As a result of a "first approximation", 38 globular clusters were selected for which the values of the color excesses were particularly reliable. The $(B-V)_0$ values, corrected for the color excess, were compared with the spectral classes of clusters, and preliminary values of E (B-V) were determined and combined with the previous values obtained by other methods. This was the beginning of the "second" approximation.

Then the following relationships were determined, which were necessary for further approximations:

$$X = \frac{E(U-B)}{E(B-V)}, \quad Y = \frac{E(V-I)}{E(B-V)}, \quad Z = \frac{E(U-B)}{E(V-I)} . \tag{52}$$

For this purpose, all of the 38 globular clusters we selected were divided into five groups, within which the spectral classes were quite similar to each other. For each of the five groups, equations of the following form were solved

$$(U-B) = a + b(B-V), \quad (V-I) = c + d(B-V), \quad (U-B) = e + f(V-I) \tag{53}$$

The values of X',Y',Z' obtained had random errors due to an inprecise knowledge of the initial values of the equations. However, the unknown values were related with each other by the precise Equations (52). For the five average spectral classes corresponding to the five groups of clusters mentioned above, the observed values of X', Y', Z' were made to correspond to

Equations (52) by successive approximations. The values thus obtained were expressed graphically as a function of the spectral class of the clusters, and they were used to draw smooth curves. Then the procedure of making the values of X", Y", Z" obtained from the graph coincide with Equations (52) was repeated for the entire interval of observed integral spectra of the clusters. Finally, the following values of X,Y,Z were obtained for the entire range of spectral classes which are characteristic for globular clusters. These values are given in Table 1 and are expressed graphically in Figure 2. /43

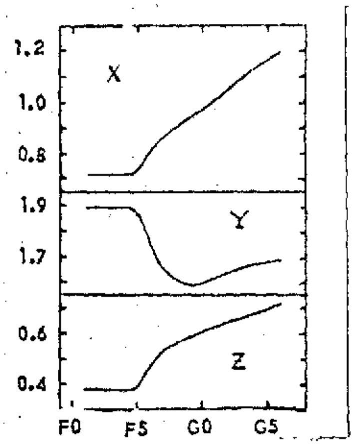

Figure 2. Behavior of the quantities $X=(U-B)/(B-V)$, $Y=(V-I)/(B-V)$, $Z=(U-B)/(V-I)$ as a function of the spectral type.

TABLE 1

Sp	X	Y	Z
F1	0.72	1.89	0.38
F2	0.72	1.89	0.38
F3	0.72	1.89	0.38
F4	0.72	1.89	0.38
F5	0.73	1.86	0.39
F6	0.82	1.74	0.47
F7	0.87	1.65	0.53
F8	0.91	1.62	0.56
F9	0.94	1.59	0.59
G0	0.98	1.60	0.61
G1	1.02	1.62	0.63
G2	1.05	1.64	0.64
G3	1.10	1.66	0.66
G4	1.14	1.67	0.68
G5	1.17	1.68	0.70
G6	1.20	1.69	0.71

Knowing the color excesses E (B-V) and using the values in Table 1, we may determine the color excesses E(U-B) and E(V-I) for all clusters having measurements in the U,B,V,I systems. By subtracting these excesses from the observed values of (B-V), (U-B), (V-I), we obtain the preliminary true values of $(B-V)_0$, $(U-B)_0$, $(V-I)_0$.

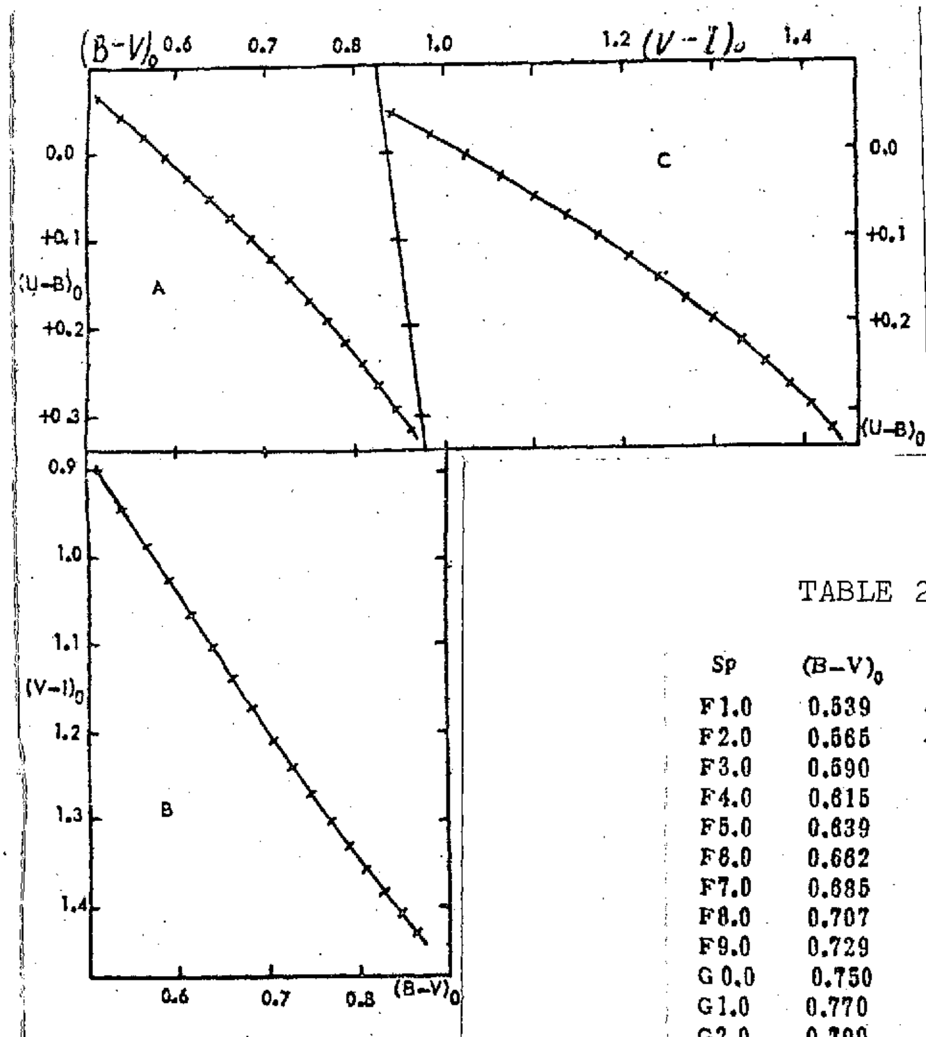

Figure 3. Relationship between the true color equivalents $(U-B)_0$, $(B-V)_0$ and $(V-I)_0$ of globular clusters.

TABLE 2

Sp	$(B-V)_0$	$(U-B)_0$	$(V-I)_0$
F1.0	0.539	−0.042	0.944
F2.0	0.565	−0.019	0.986
F3.0	0.590	0.004	1.026
F4.0	0.615	0.027	1.064
F5.0	0.639	0.050	1.102
F6.0	0.662	0.074	1.138
F7.0	0.685	0.098	1.173
F8.0	0.707	0.122	1.207
F9.0	0.729	0.146	1.240
G0.0	0.750	0.170	1.271
G1.0	0.770	0.194	1.301
G2.0	0.790	0.219	1.330
G3.0	0.809	0.244	1.357
G4.0	0.828	0.269	1.384
G5.0	0.846	0.294	1.409
G6.0	0.863	0.320	1.433

It is apparent that the values of the true color equivalents of globular clusters are related with their integral spectral classes. Therefore, equations of the following type were solved:

$$\left\{\begin{aligned} (B-V)_0 &= a + b\,Sp + c\,Sp^2 \\ (U-B)_0 &= d + e\,Sp + f\,Sp^2 \\ (V-I)_0 &= g + h\,Sp + k\,Sp^2, \end{aligned}\right. \qquad (54)$$

where the left sides are known as a result of the calculations just described, and the right sides contain values of the spectral classes (see the preceding section). The new values of the color excesses, obtained by the solution of these equations, were averaged with the previous redetermined values which were independent of them. The true color equivalents were determined with the improved values, and again the system of Equations (54) was solved.

As a result of the successive approximations described here, the following numerical expressions of Equations (54) were used

$$(B-V)_0 = \underset{\pm 0.014}{0.513} + \underset{\pm 0.039}{0.267}\,Sp - \underset{\pm 0.023}{0.030}\,Sp^2 \quad (55)$$

$$(U-B)_0 = \underset{\pm 0.025}{-0.065} + \underset{\pm 0.071}{0.226}\,Sp + \underset{\pm 0.042}{0.009}\,Sp^2 \quad (56)$$ /44

$$(V-I)_0 = \underset{\pm 0.030}{0.902} + \underset{\pm 0.083}{0.431}\,Sp - \underset{\pm 0.049}{0.062}\,Sp^2 \quad (57)$$

Using these equations, we may formulate the direct dependences between the values $(B-V)_0$, $(U-B)_0$, $(V-I)_0$. These dependences are given in Table 2, and are expressed graphically in Figure 3. /45

Knowing the observed values of the color equivalents of globular clusters in the U,B,V,I system, as well as the integral spectral classes, and using the values from Tables 1 and 2 for each cluster, we may find the color excesses which satisfy in an optimum way the numerical values of all the quantities used. If there is no spectral class, we may select its value which satisfies in an optimum way the observed values of the color equivalents.

Recently R. Racine, 1973, used a similar method for the color equivalents B-V, U-B. This method was criticized by B. V. Kukarkin and N. N. Kireyev, 1973. We would like to note that the statements of Racine regarding the fact that the color equivalents are not suitable for determining the contents of metals in the atmospheres of stars and globular clusters is not correct. The blanketing effect unavoidably is included in the value X in Equation (52). The values of $(B-V)_0$, $(U-B)_0$ are actually free to a considerable extent from the blanketing effect both as given by Racine and by the authors. However, in the observed values of all color equivalents, the blanketing effect is fully apparent, and they are suitable for a reliable determination of the content of metals. The appropriate formulas are derived in the chapter of this book devoted to the problem of "Metallicity" of globular clusters.

A more rigorous solution of the problem of the true color equivalents of globular clusters requires the concurrent examination of the influence of both temperature and chemical composition of the atmosphere upon them. This problem did not lie within the framework of the present investigation; however, we hope to study this problem in the future. The values of the color equivalents selected here are suitable for solving many practical problems related to interstellar absorption, chemical composition, etc.

Color excesses and interstellar absorption of light

In the preceding chapters of the book, we have already repeatedly discussed the color excesses and interstellar absorption of light in globular clusters. In this short chapter of the book we shall describe the methods to obtain the excesses of the color equivalent E (B-V) used in our studies and published in the appropriate column of Table D at the end of the book.

The main source for the numerical determinations of E(B-V) was a comparison of the observed values of B-V, U-B, V-I with the true values (see the preceding chapter of the book) and the determination of the optimum value which satisfies all conditions in the best way.

A secondary source was a study of the color-luminosity diagrams and their comparison with the diagrams of the well-studied clusters 47 Tuc, M3, M92 and others, for which E (B-V) is small and is known. This method, which is widely used by many researchers, is very sensitive to the axiomatics lying at the basis of the selection of points and sequences which are suitable for this purpose (blue and red end of the band of stars of the RR Lyrae type, the point of rotation from the branch of the giants to the main sequence, the point of intersection of the horizontal branch and the branch of the giants, the average value of (B-V) for stars of the RR Lyrae type, etc.) /46

The third source was certain theoretical relationships which determine the true color equivalent of certain points.

Finally, the absorption of light was determined for certain clusters based on the color excesses of surrounding stars, if their spectra were known in the two-dimensional MK classification.

Just as in the case of determining the spectral classes, it was difficult to make a precise estimate of the average errors and the weights of all the values of the color excesses used. The mean square error was determined from the deviations of a given series of E (B-V) values from the preliminary average values, and the weight was established. Then the weighted average was calculated. Repeating this procedure only changed the weight to an insignificant extent, and in the majority of cases, it was not done. A unit of weight corresponds to a mean square error of E (B-V) $\pm 0.^{m}10$.

6. CONTENT OF METALS IN THE ATMOSPHERES OF STARS IN GLOBULAR CLUSTERS /47

The problem of studying the chemical composition of the atmospheres of stars in globular clusters is no less complex than the problem of determining the true color equivalents and color excesses. The same criteria must be applied to the composite total integral spectra of globular clusters as are applied to individual stars, i.e., they are not corrected. Attempts to determine the chemical composition based on the spectra of individual stars were only made for a few globular clusters. However, this is not entirely valid.

Achievements in the development of a theory for the internal structure of stars with masses less than 1.5 of the solar mass and calculations of different models have led to the conclusion that many characteristics of the color-luminosity diagrams are correlated with the content of heavy elements and helium. This provides additional possibilities of determining the content of heavy elements.

Electrophotometry in the U,B,V,I system, intermediate-band and narrow-band photometry also provide specific information.

However, it must always be remembered that all the methods mentioned above for determining the chemical composition depend on many parameters and cannot be regarded as unequivocal, objective, and sufficiently accurate. They all include systematic errors.

In this connection, the decision was made to select a uniform scale which is approximately linearly related with the logarithm of the relative (as compared with the Sun) content of metals. All of the available methods for determining the content of metals were included, in the hope that with a sufficient number the systematic errors inherent to them could be regarded as random.

A. J. Deutsch, 1955, was the first to pay serious attention to the relative paucity of metals in globular star clusters. Later W. W. Morgan, 1959, noted that the integral spectra of globular clusters also had characteristics related to the content of metals. The studies of T. Kinman, 1959 b, and H. Arp, 1959, as well as several others, were also devoted to these problems.

At the beginning of the 1960's, in Moscow an attempt was made to reduce all of the accumulated determinations of "metallicity" to an arbitrary scale which was proportional to the logarithm of the relative content of metals. All of the published determinations of the content of metals were later reduced to this arbitrary scale. Finally, the work of Rusev and the author, (B. V. Kukarkin, et al., 1972) published preliminary values of the metallicity indices (MI). During the numerous reductions of several determinations of the relative content of metals, our arbitrary scale of the MI required a new calibration, which was done recently, (B. V. Kukarkin, 1973). /48

In a subsequent section we shall describe all of the determinations of the content of metals in globular clusters which we used, or the values quantitatively related with the content of metals. Methods are described for reducing the corresponding logarithm of the content of metals with respect to the Sun to the value of [m/H] which we used.

The mean square deviation for each series of determinations was determined by studying the deviations of the reduced values from the preliminary average values. The weight was determined on the basis of these estimates of the mean error. The relative reliability of the determination was taken into account in each of the series. The unit of weight corresponds to the mean square error ±0.10 in [m/H].

1. Classes of W. W. Morgan, 1959.

Morgan divided the entire set of globular clusters which he examined into eight classes designated by Roman numerals, so that I corresponded to the smallest relative content of metals and VIII- to the largest. The dependence of [m/H] on the classes of Morgan is tabulated in the following table

I −2.13	II −1.58	III −1.26	IV −0.98
V −0.72	VI −0.28	VII −0.15	VIII + 0.04

The mean square error of determining [m/H] of one cluster is ±0.22.

2. Determination of the relative content of metals based on the spectra of individual cluster stars (T. D. Kinman, 1959 b.)

A determination of the content of metals by studying the spectra of known members of globular clusters would be a direct method of studying the problem. Unfortunately, a reliable study of the spectra with great dispersion is still impossible due to the weakness of even the brightest members of the globular clusters. Therefore, Deutsch and Kinman were forced to confine themselves to a study of spectra with low dispersion. Based on the proposal of Deutsch, the measurement results were divided into three groups: A, B and C. The first of these groups (A) corresponds to clusters whose stars have the largest metal content, and the last group (C)— the least metal content. The average values of [m/H] in our system are given in the following table for each of these groups, separately from the determinations of Deutsch and Kinman. A certain difference in the values of [m/H] of both authors should not be surprising. There were three total clusters in all (based on one in each group), so that the selections consisted of different objects, and, with a small number of clusters in each group, a random accumulation of systematic deviations is fully possible due to the significant dispersion in each of the groups. / 49

	A	B	C
Deutsch	−1.33	−1.69	−2.10
Kinman	−0.90	−1.61	−1.90

The mean square error of measuring [m/H] of one cluster is ±0.20.

3. Difference in spectral classes determined from the lines of hydrogen and iron (W. W. Morgan, 1956; T. D. Kinman, 1959b).

The difference between the determinations of the spectral class based on the lines of hydrogen and iron, usually designated by the symbol ΔS, may also be a measure of metallicity. Each of the two examined series of observations was compared with the preliminary values of [m/H] by compiling graphs. They were used to obtain the values tabulated in the following table:

ΔS (Morgan)	−3	3	6	7	8	9			
[m/H]	+0.06	−0.75	−1.16	−1.30	−1.43	−2.00			
ΔS (Kinman)	0	1	2	3	4	6	7	8	9
[m/H]	−0.90	−1.01	−1.12	−1.23	−1.34	−1.56	−1.67	−1.78	−2.00

The mean square error of determining [m/H] of one cluster is ±0.39.

4. Spectrophotometric values of $\bar{\Delta}$, ϕ and ψ (S. van den Bergh and G. L. Hagen, 1962).

All of the three values mentioned in the heading are related with the value [m/H]. The following five equations were obtained graphically:

$$[m/H] = 4.92\bar{\Delta} - 2.68 \tag{58}$$

$$\left.\begin{array}{ll} [m/H] = 6.8\Phi - 2.88 & > 0.19 \\ [m/H] = 13.0\Phi - 3.96 & < 0.19 \end{array}\right\} \tag{59}$$

$$\left.\begin{array}{ll} [m/H] = 2.76\psi - 2.64 & \leqslant 0.48 \\ [m/H] = 5.1\psi - 3.76 & > 0.48 \end{array}\right\} \tag{60}$$

The mean square errors of determining [m/H] of one cluster are ± 0.28, ± 0.26 and ± 0.20.

5. Intermediate band photometry (R. D. McClure and S. van den Bergh, 1968)

The color equivalents $C^*(38-41)$ and $C^*(41-42)$, corrected for interstellar reddening, were found to have the best relationship with the values of [m/H] out of the color indices of five-color intermediate band photometry of globular clusters. The following four equations were obtained graphically:

$$\left.\begin{array}{ll} [m/H] = 8.2\ C^*(38-41) - 5.09, & C^*(38-41) \leqslant 0.50 \\ [m/H] = 5.06\ C^*(38-41) - 3.51, & C^*(38-41) > 0.50 \end{array}\right\} \tag{61}$$

$$\left.\begin{array}{ll} [m/H] = 48.0\ C^*(41-42) - 3.87, & C^*(41-42) \leqslant 0.058 \\ [m/H] = 14.3\ C^*(41-42) - 1.91, & C^*(41-42) > 0.058 \end{array}\right\} \tag{62}$$

The mean square errors of determining [m/H] of one cluster are ± 0.22 and ± 0.51, respectively. /50

6. Narrow band photometry (H. L. Johnson and D. H. McNamara, 1969)

The preliminary values of [m/H] are represented very well by an equation which includes the values of $[m_1]$ and $[c_1)$ corrected for interstellar absorption

$$[m/H] = \underset{\pm 2.4}{15.8}\,[m_1] + \underset{\pm 2.0}{6.8}\,[c_1] - 6.3 \tag{63}$$

The mean square error of determining [m/H] of one cluster is ± 0.20.

7. Measurements of the spectra based on lines of different elements (S. van den Bergh, 1969).

The value of L is closely related to the value of [m/H]. The following table gives the values taken from the graph:

L	[m/H]	L	[m/H]	L	[m/H]	L	[m/H]
−1	−2.31	3	−1.42	7	−0.77	11	−0.14
0	−2.09	4	−1.23	8	−0.62	12	+0.01
1	−1.87	5	−1.08	9	−0.46	13	+0.17
2	−1.64	6	−0.93	10	−0.30	14	+0.33

The mean square error of determining [m/H] of one cluster is ±0.24.

8. The quantity Δ (U-B)(O. J. Eggen, 1972).

During the photometric measurements of stars in several globular clusters, O. J. Eggen determined the quantity Δ (U-B) related with the values of [m/H] by the following equation (obtained graphically)

$$[m/H] = -2.76\,\Delta(U-B) - 0.03 \tag{64}$$

The mean square error of determining [m/H] of one cluster is ±0.35.

9. Ten-color intermediate band photometry (S. M. Faber, 1973).

The values of $(Mg)_0$ and $(38\text{-}41)_0$, corrected for interstellar absorption, had the most explicit dependence on [m/H] out of all the different combinations of measurements by Faber. They are connected with [m/H] by the following equations (obtained graphically)

$$[m/H] = -16.6\,(Mg)_0 - 1.71 \tag{65}$$

$$[m/H] = 6.2\,(38-41)_0 - 4.89 \tag{66}$$

The mean square errors of determining [m/H] cluster are ±0.21 and ±0.10, respectively.

10. Determination of the relative content of metals based on wide band photometry of U, B, V, I (this paper).

/51

As was illustrated recently (B. V. Kukarkin, N. N. Kireyeva, 1973, regular photometry is suitable for determining the relative content of metals, in spite of the doubts indicated by R. Racine, 1973. The following equations were obtained based on the values of the color equivalents (B-V), (U-B) and (V-I) given in this study (see Table C) and as a result of comparing them with the preliminary values of [m/H]:

$$[m/H] = 0.61 + \underset{\pm 1.1}{5.6}\,(U-B) - \underset{\pm 1.2}{3.9}\,(B-V) \qquad (67)$$

$$[m/H] = 0.10 + \underset{\pm 0.8}{4.8}\,(U-B) - \underset{\pm 0.5}{1.8}\,(V-I) \qquad (68)$$

$$[m/H] = 0.43 + \underset{\pm 0.9}{5.3}\,(U-B) - \underset{\pm 0.3}{1.3}\,(B-I) \qquad (69)$$

These formulas for calculating Q are given in the work of B. V. Kukarkin, N. N. Kireyeva, 1974. The mean square errors of determining [m/H] of one cluster are ± 0.27, ± 0.25 and ± 0.26, respectively.

11. The relationship between the independent determinations of [m/H] and the spectral classes.

It has been repeatedly noted that the spectral classes of globular clusters are connected with the content of metals. This is of both negative and positive importance. The negative aspect consists primarily of the fact that in many cases it is very difficult to separate the influence of temperature (spectrum) from the influence of chemical composition upon different photometric measurements, particularly in the cases of wide band photometry. The positive aspect consists primarily of the fact that both of these values are mutually controlled by the other, and this fact may be employed. This is particularly important when there is no, or insufficient, other information.

A comparison of the most reliable determinations of [m/H] with the most reliable determinations of the spectral classes gives the following equation (spectral class F0.0 is arbitrarily assumed to be 0.00, and spectral class G0.0 — 1.00):

$$[m/H] = \underset{\pm 0.07}{-2.40} + \underset{\pm 0.09}{1.70} (Sp - F0.0) \tag{70}$$

The opposite problem was solved — determining the spectral class based on the value of [m/H]:

$$(Sp - F0.0) = \underset{\pm 0.04}{1.44} + \underset{\pm 0.03}{0.59} [m/H] \tag{71}$$

The mean square errors of determining the corresponding values of one cluster equal ± 0.15 and ± 0.09. However, these estimates are formal in nature, i.e., both quantities are related with each other statistically. These errors were not used in determining the weights. The weight was determined arbitrarily, using the deviations from the average values. /52

In recent years there have been numerous publications of studies of the evolution of stars with masses equal to, or less than, the solar mass at later stages of development, as well as the linear and nonlinear theory of pulsation. Let us note, for example, the studies of Albada, T.S. van, et al., 1973, Christy, R. F., 1966, Demarque, P. R. et al., 1963, Demarque, P. R., et al., 1972, Iben, I. Jr., 1971, Iben, I. Jr. et al., 1970, Rood, R. T., 1970, Rood, R. T., 1973.

Repeated comparisons were made in these studies of the conclusions of the theory with the observations, particularly the characteristics of the Hertzsprung-Russell diagrams (they will be designated by the symbol H-R below, for purposes of simplicity). Certain characteristics of these diaphragms connected with the chemical composition were predicted (content of metals, content of helium, etc.). Just as in the case of spectral and photometric determinations of the content of metals, all the characteristics (probably even to a great extent) are related with the axiomatics lying at the basis of the corresponding theoretical calculations. However, in several cases, the connection between the content of metals and certain characteristics "predicted" theoretically was known before this (for example, the curvature of the branch of the giants on the H-R diagram, the population of the blue and red portion of the horizontal branch, etc.). All of this calls particular attention to the similar relationships, and attempts are made to use them for determining the relative content of metals in the stellar population of the globular cluster.

Formulas or tabular values relating several characteristics of the H-R diagram and other physical characteristics of stars in globular clusters with the chemical composition of their atmospheres are examined and derived below.

1, 2, 3. Characteristics of the branch of the giants in globular clusters

It was recently found that the value ΔV, designating the difference between the stellar magnitudes on the horizontal branch and the same point on the branch of the giants, which corresponds to the value $(B-V)_0 = +1^m.40$, is not identical, and is correlated with the content of metals. The correlation with the content of metals occurs at the point of intersection of the horizontal branch and the branch of the sub-giants, corrected for the color excesses $E(B-V)$, designated by the symbol $(B-V)_{0,g}$. Several years ago the single characteristic S was introduced (F.D.A. Hartwick, 1968), which represents, in the words of Hartwick, the "inclination of the line connecting the point of intersection of the horizontal branch with the branch of the sub-giants and the point on the branch /53 of the giants $2^m.5$ above the horizontal branch". This is simply the tangent of the angle between the lines mentioned in the quotation multiplied by 2.5. Hartwick stresses that the value of S does not depend on allowance for the color excess, and therefore is to be preferred to the value of ΔV. However, in principle, this is not true, i.e., the color excess depends on the color itself, particularly in the case of large values of (B-V) which are characteristic for stars on the branch of the giants. In addition, the accuracy of determining S decreases greatly with an increase in the curvature of the branch of the giants, i.e., a small error in determining the point of intersection of the horizontal branch with the branch of the sub-giants has an insignificant influence in the case of a small inclination, but has a very great influence in the case of steep inclinations. Nevertheless, we decided to use the value of S.

There is always a certain arbitrary element in determining the values ΔV, S and $(B-V)_{0,g}$. In order to reduce this to a minimum, independent determinations of these values were made twice over a long period of time. Then all the determinations from the literature were selected. In addition, certain of these values were determined independently by my coworkers, N. N. Samus' and A. V. Mironov. The average of three determinations was selected. Below Table 3 gives the values of all three quantities which we used, as well as the magnitude of the stars on the horizontal branch. A subjective estimate of the degree of reliability is given after each value (the highest is 4).

We then studied the dependence of [m/H] on these three characteristic H-R diagrams (the graphic method was used).

The value of ΔV is related with [m/H] by the following equations:

$$\left.\begin{array}{ll} [m/H] = 3.54 - 1.96\,\Delta V, & \Delta V < 2.32 \\ [m/H] = 1.89 - 1.26\,\Delta V, & \Delta V \geq 2.32 \end{array}\right\} \qquad (72)$$

The mean square error of determining [m/H] of one cluster is ± 0.28.

The dependence of [m/H] on S was formulated graphically and tabulated in the following table:

S	[m/H]	S	[m/H]	S	[m/H]	S	[m/H]
2.6	+0.18	3.8	−0.99	5.0	−1.58	6.2	−1.99
2.8	−0.02	4.0	−1.09	5.2	−1.67	6.4	−2.05
3.0	−0.22	4.2	−1.19	5.4	−1.74	6.6	−2.11
3.2	−0.41	4.4	−1.29	5.6	−1.80	6.8	−2.18
3.4	−0.61	4.6	−1.38	5.8	−1.87	7.0	−2.24
3.6	−0.81	4.8	−1.48	6.0	−1.93		

The mean square error of determining [m/H] of one cluster is ± 0.35.

The dependence of [m/H] on $(B-V)_{0,g}$ may be represented by two equations (obtained graphically):

$$[m/H] = 6.75\,(B-V)_{0,g} - 6.57, \quad (B-V)_{0,g} \geqslant 0.74$$
$$[m/H] = 2.70\,(B-V)_{0,g} - 3.67, \quad (B-V)_{0,g} \leqslant 0.74 \qquad (73)$$

The mean square error of determining [m/H] of one cluster is ± 0.37.

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4. Population of the horizontal branch of the Hertzsprung-Russell diagram

It has already become apparent that the horizontal branch of the H-R diagram in different globular clusters is not the same. About 15 years ago (1959) in Moscow, a classification of globular clusters was proposed based on the form of the horizontal branch. A relationship was found between the form of the horizontal branch and the content of metals. A continuous scale of numbers characterizing the population of the horizontal branch was developed. A. V. Mironov (1972, 1973), and A. M. Eigenson, 1973, published several investigations devoted to the problem of the

TABLE 3

Cluster	ΔV		S		$(B-V)_{0,g}$		HB	
104	2.03	3	3.38	3	0.89	3	14.06	2
362	2.28	2	3.64	2	0.81	2	15.48	1
1261	2.68	1	4.52	1	0.79	1	16.60	½
1851	2.26	1	4.31	1	0.93	1	15.81	1
2298	3.13	1	5.55	1	0.70	1	16.20	1
2808	3.10	1	4.63	1	0.57	½	16.90	1
3201	2.80	1	4.93	1	0.65	1	14.88	1
Pal 4	2.67	1	4.56	1	0.74	1	20.50	1
4147	2.49	1	5.45	1	0.80	1	16.82	1
4372	3.10	2	6.10	2	0.78	2	15.58	2
4833	3.05	1	5.14	1	0.71	1	15.47	1
5024	2.88	1	5.07	1	0.71	1	16.83	1
5053	3.2	½	4.73	1	0.64	1	16.65	½
5139	2.86	4	5.26	4	0.78	4	14.48	4
5272	2.70	3	5.00	3	0.79	3	15.64	4
5466	3.08	1	5.49	1	0.64	1	16.53	2
5897	2.79	1	5.00	1	0.76	1	16.21	1
5904	2.66	2	4.42	2	0.78	2	15.10	2
6121	2.18	1	3.20	1	0.79	1	13.32	1
6171	2.28	3	4.03	3	0.89	3	15.64	3
6205	2.61	3	4.86	3	0.80	3	14.76	3
6218	2.89	1	5.74	1	0.77	1	14.94	1
6254	2.65	1	5.38	1	0.82	1	14.72	1
6341	3.10	3	6.79	3	0.69	3	15.08	3
6352	1.62	1	2.9	½	0.97	1	15.12	1
6356	1.98	1	2.56	1	0.85	1	17.68	1
6362	2.45	2	4.61	2	0.90	2	15.28	2
6397	2.56	1	5.08	1	0.84	1	12.58	1
6402	2.03	2	3.03	2	0.74	2	17.25	2
6522	2.26	1	3.57	1	0.85	1	16.26	1
6528	1.7	½	3.2	½	1.0	½	17.2	½
6541	2.84	1	6.60	1	0.81	1	15.0	1
6553	-		3.0	1	0.98	½	-	
6637	1.52	1	3.16	1	0.98	1	16.25	1
6656	2.62	1	3.72	1	0.64	1	14.05	1
6712	2.23	1	4.54	1	0.91	1	16.10	1
6723	2.09	2	3.79	2	0.87	2	15.52	2
6752	2.91	3	6.68	3	0.81	2	13.99	3
6779	3.02	1	4.63	1	0.58	1	16.20	1
6838	1.97	1	3.22	1	0.87	1	14.49	1
6934	2.92	2	6.81	2	0.81	2	16.84	2
6981	2.81	1	4.87	1	0.74	1	16.87	1
7006	2.65	1	4.44	1	0.74	1	18.74	1
7078	3.27	2	7.07	2	0.73	2	15.66	2
7089	2.90	1	6.78	1	0.75	1	15.91	1
7099	3.01	1	4.75	1	0.66	1	15.10	1
Pal 13	-		-		0.9	½	17.70	1
7492	2.32	2	3.20	2	0.74	2	16.98	2

population of the horizontal branch.

In 1972, independently of the authors, a similar classification was proposed by R. J. Dickens, 1972, who divided the entire set of globular clusters into seven classes.

The scale developed in Moscow represents a continuous series of numbers from zero to one. The number 0 corresponds to the absolute absence of stars in the red portion of the horizontal branch and the greatest density of stars close to the blue end of the branch. The complete absence of the horizontal branch was used as unity. It is apparent that, among the observed diversity of globular clusters, there is not one corresponding to the maximum values of our scale.

Estimates of the population of the horizontal branches of globular clusters are very subjective, even when attempts are made to calculate the stars and estimate their density in the (B-V) intervals. This is due to the fact that it is difficult to develop unified principles for determining the red boundary of the horizontal branch and to precisely establish whether stars belong to this branch. Different diagrams were formulated based on observations of differing accuracy and, in spite of the fact that they cannot be used for precise measurements, they are fully satisfactory for inprecise measurements.

In order to decrease the influence of the subjective factor to a certain extent, estimates "of the index of relative population" K of the horizontal branches were carried out several times over long time periods. The classes of Dickens and the values of B/(B+R) of Mironov were reduced to our K scale. Finally, the /56
values proposed for K are given in Table 4. An estimate of the reliability, given in a six-scale system, is given along with K: the most reliable estimates are given a weight of 6, and the least

reliable estimates are given a weight of 1, while those in doubt are given a weight of 1/2.

TABLE 4

Cluster	K		Cluster	K		Cluster	K		Cluster	K	
104	0.81	6	5053	0.13	2	6352	0.78	5	6712	0.60	6
288	0.02	1	5139	0.13	6	6356	0.82	5	6723	0.54	6
362	0.69	5	5272	0.46	6	6362	0.49	4	6752	0.10	6
1261	0.56	4	5466	0.16	4	6397	0.14	5	6779	0.11	5
1851	0.71	4	5897	0.11	6	6402	0.18	3	6838	0.77	5
2298	0.47	1	5904	0.32	6	6522	0.78	3	6934	0.33	3
2808	0.5 ?	½	6121	0.43	5	6541	0.13	4	6981	0.42	5
3201	0.48	4	6171	0.70	6	6553	0.86	1	7006	0.60	6
4147	0.25	6	6205	0.05	6	6637	0.80	5	7078	0.22	6
4372	0.22	2	6218	0.09	6	6656	0.11	6	7089	0.12	6
4833	0.07	6	6254	0.12	6				7099	0.13	5
5024	0.14	6	6341	0.10	6				7492	0.18	5

A comparison of the values of [m/H] with our K values led to the following reduced quantities obtained graphically:

K	[m/H]	K	[m/H]	K	[m/H]	K	[m/H]
0.00	−1.81	0.25	−1.60	0.50	−1.24	0.70	−0.73
0.05	−1.79	0.30	−1.54	0.55	−1.14	0.75	−0.54
0.10	−1.75	0.35	−1.48	0.60	−1.02	0.80	−0.31
0.15	−1.70	0.40	−1.41	0.65	−0.89	0.85	−0.05
0.20	−1.65	0.45	−1.33				

The mean square error of determining [m/H] of one cluster is ±0.26.

5. Transition periods of stars of the RR Lyrae type

In the development of a theory of the pulsations of variable stars, using a specific axiomatic procedure, Christy determined the relationship between the transition period (between oscillations in the main tone and in the first overtone) Ptr, and the luminosity of stars of the Lyrae type (R. F. Christy, 1966). This conclusion was repeatedly subjected to criticism, since the luminosity of stars of the RR Lyrae type

(as well as other pulsating stars) depends not only on the factors taken into account by Christy (Albada, T. S. van, et al., 1973; Rood, R. T., 1973). We distrusted the conclusions of Christy to a certain extent. However, a random comparison of the value of the transition period P_{tr} with our metallicity indices MI (Kukarkin, B. V., Russev, R. M., 1972) unexpectedly led to a close interrelationship between them. As is known, the metallicity indices are derived by methods which are not in any /57
way related with the theory of pulsations, and the fact that a relationship was found is strong proof of the fact that the formula of Christy has statistical meaning in every case, although in individual cases it may lead to luminosity values which deviate from the true values. We used the values of the transition periods P_{tr} after reviewing all of the observations of stars of the RR Lyrae type in globular clusters. Only those clusters were selected in which the number of stars of the RR Lyrae type equaled or exceeded ten. To a certain extent, this protected us from a random selection. To determine P_{tr}, the Christy formula was used:

$$P_{tr} = \frac{1}{2}\left(P_{ab}^{min} + \frac{4}{3}P_{c}^{max}\right) \qquad (74)$$

Not one but two stars were selected to determine the limiting values of the smallest periods of stars of the RRab type and the largest periods of the RRc stars. This also decreased the influence of random selection to a certain extent. Table 5 gives the values which we usedfor the logarithms of the transition periods P_{tr} for different globular clusters. We have not introduced the reliability signs, although it is apparent that the probability of great accuracy of a transition period on the basis of selecting from 200 stars exceeds the probability of the same accuracy on the basis of selecting 10 stars. In addition to this, after the value of log P_{tr}, Table 5 gives the number of stars of the RR Lyrae type. The values of the periods were usually selected from the Sawyer catalog (H. B. Sawyer-Hogg, 1973), but always were checked in the original sources and were changed in certain cases.

TABLE 5

Cluster	lg Ptr	n	Cluster	lg Ptr	n	Cluster	lg Ptr	n
3201	−0.315	82	5904	−0.337	90	6402	−0.316	34
4147	−0.297	16	6121	−0.360	40	6656	−0.228	17
4590	−0.257	37	6171	−0.362	21	5715	−0.311	31
5024	−0.275	36	6229	−0.327	15	6723	−0.370	27
5053	−0.231	10	6266	−0.352	74	6934	−0.340:	30
5139	−0.253	125	6333	−0.293	10	6981	−0.322	27
5272	−0.331	178	6341	−0.242	12	7006	−0.293:	36
5466	−0.260	20	6362	−0.314	14	7078	−0.250	63
						7089	−0.305	17

A comparison of the values of [m/H] with the lg P_{tr} values from Table 5 resulted in the following formula:

$$[m/H] = \underset{\pm 0.30}{-3.71} \underset{\pm 1.00}{- 7.52} \lg P_{tr} \qquad (75)$$

The mean square error of determining [m/H] of one cluster is ±0.20.

The weighted mean values were calculated on the basis of all the methods described above for determining the content of metals [m/H]. They are given in Table D at the end of the book. Just as in other cases, the unit of weight corresponds to the mean square error ±0.10 in [m/H]. /58

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7. DIAMETERS OF GLOBULAR CLUSTERS

Three-dimensional structure of globular clusters

The first initial information about globular clusters included the assumption of the relative uniformity of their structure: circular form, central symmetry. However, a more careful study of the structure of globular clusters showed that it is complex and not so uniform.

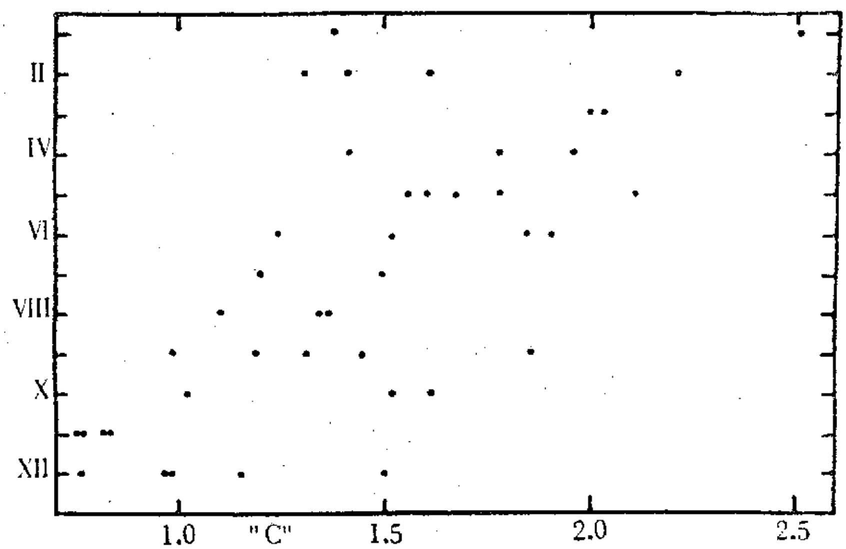

Figure_4. Weak dependence between "concentration classes" of Shapley-Sawyer and the characteristic of the real concentration of stars in the "C" clusters according to King.

Forty years ago H. Shapley, et al., 1927, made the first attempt to classify globular clusters based on the degree of concentration of stars in the clusters. It is true that it was later found that their classification is more correctly related to luminosity (mass) of the clusters and only in a certain sense with the real concentration (see, for example, B. V. Kukarkin, 1971). This was confirmed to a certain extent in a comparison of the concentration classes of Shapley-Sawyer with a more objective determination of the "C" concentration (I.R. King, 1974). As may be seen in Figure 4, there is only a weak correlation between both quantities.

We shall not discuss earlier studies devoted to the development of [numerical] methods of determining the three-dimensional density of stars in the clusters. /60

A. G. Mowbray, 1946, made an important, thorough, but almost careless study of globular clusters. He introduced a clear distinction between the nucleus and the overall body of globular clusters. Mowbray may now be considered as one of the most important researchers based on his careful processing and uniformity of the material used. The correlation of his concentration classes with the "C" values of King is much more clearly apparent than with the classes of Shapley-Sawyer.

The studies of P. N. Kholopov, 1949, 1952, 1953, 1957, 1965, 1968a, 1968b, are very important for understanding the structure of globular clusters. These studies definitely showed that the clusters represent complex, stratified structures in which a central nucleus, the main body, and an intermediate zone and corona may be clearly distinguished. Unfortunately, only a few clusters were subjected to a careful analysis, and it is difficult to use these rigorous studies to calibrate the mass measurements of structural characteristics of globular clusters.

Beginning in 1961, King and his co-workers published several studies devoted to the theory of the structure of globular star clusters and performed photometric measurements and calculations (I. R. King, 1961; 1962; 1966a; 1966b; I.R. King, et al., 1968; I. R. King, 1974). The important concept of the limiting cluster radius was introduced, i.e., the radius beyond whose limits any star cluster will no longer be a member. Different authors have published recently many studies devoted to the dynamic development of clusters in the gravitational field of the galaxy. We would like to recall only one of them (Ostricer, J. P., et al., 1972).

In writing this book and the catalog of global characteristics, we did not study the problem of the fine structural characteristics of globular clusters. In the first place,

P. N. Kholopov had already performed several studies in this regard. Secondly, I. R. King analyzed the stars mentioned above in the 54 globular clusters. At the beginning of 1974, King kindly put at my disposal the preliminary results obtained directly from the computer. However, the book was almost ready, and we could only use a very limited volume of this material. /61

Apparent diameters (radii) of globular clusters

Among the global characteristics of globular clusters, the diameters are one of the most difficult quantities to determine. This is due to the complexity of the cluster structure, and the difficulty of making a simple determination of both the radius of the nucleus and the limiting radius.

If we do not consider incidental studies which make an attempt to measure the diameters of globular clusters, the first systematic studies performed in more or less uniform systems undoubtedly belong to H. Shapley. They were completed in three studies encompassing almost all of the globular clusters known at that time (H. Shapley, et al., 1927b; H. Shapley, 1930; H. Shapley, et al., 1935). The first two used the method of visual determination of the diameter based on three series of points from the Harvard Observatory. The third study is based on measurements of the plate background by means of a microphotometer (the diameter was assumed to be the region in which the surface density of the cluster star equaled the background).

In 1941 P. Parenago, B. Kukarin and N. Florya analyzed all of the data published up to that time on the apparent magnitudes, color equivalents, and diameters of globular clusters. A clearly expressed dependence was found for all of the measured apparent diameters of globular clusters on the magnitude of interstellar light absorption. The war stopped the publication of this work, and it came to light only 8 years later (P. Parenago, et al., 1949). Four years later W. Lohmann, using the ideas in our study and adding new data appearing after 1941, completely confirmed our conclusions (W. Lohmann, 1953). It is interesting that neither the review of H. Sawyer Hogg, 1959 or that of H. Arp, 1965, mentioned our study, but the problem was discussed in the study of Lohmann, and he clearly referred in detail to the primary source.

The very interesting study of H. Wilkens, 1960, investigated the influence of interstellar absorption of light upon the measurement of apparent diameters of globular clusters. Later Wilkens studied the problem of globular cluster diameters. His study is a separate publication, given as an appendix to the collection "Variable Stars".

At the very beginning of the study, the question arose of selecting the system in the problem of the diameters of globular star clusters. Since it was difficult to wait for the end of King's study (all the remaining sections of the investigation were primarily concluded), it was necessary to use some kind of solution, in order not to delay the publication of this book. As a result, a compromise solution was used, based on the numerous previous attempts to develop a uniform and valid system of diameters. We shall now describe this system. /62

After the work of G. E. Kron and N. U. Mayall, 1960, came to light, all of the determinations published at that time of the diameters of globular clusters were reduced to their system. In actuality, electrophotometric measurements reliably record the increased emission of cluster stars with respect to the emission of the stellar background. In principle, this makes it possible to estimate the extent of the cluster. However, since equality with the background (by definition, this is the asymptote) is established in a very unreliable way, Kron and Mayall decided to use the value at which 0.9 of the entire light flux of the cluster in the V system is recorded as the cluster diameter. When the diameters of globular star clusters, which had been published up to that time, were reduced, their extreme sensitivity to the absorption of light in interstellar space was reliably confirmed. However, it must not be forgotten that the system of diameters of Kron and Mayall is not free of the influence of light absorption in interstellar space. In actuality, the distance up to the globular clusters usually greatly exceeds the distance to the stellar background, and interstellar absorption — particularly in clusters close to the galactic equator — may greatly exceed that for the background of the stars. In electrophotometric measurements in the region of noise in globular clusters, a much larger portion of the stars will "depart" than from the background stars. Thus, it is necessary to find methods for taking into account the influence of the interstellar absorption of light in the preliminary system of apparent diameters of globular clusters.

At the present time a system of diameters measured with stars of the Lyrae type, which clearly belonged to the cluster, is the only system of globular cluster diameters in which the interstellar absorption of light has no influence. The diameters of globular clusters using stars of the RR Lyrae type have already been determined (see S. Bergh, van den, 1956; H. Wilkens, 1960).

It is necessary to select a method of determining the diameters of globular clusters based on stars of the RR Lyrae type. It is apparent that it is impossible to estimate the diameter based on one very far-removed star of this type, due to the possible random nature and unreliability of this selection. It is possible to take the average distance of <u>all</u> stars of the RR Lyrae type from the center of a given cluster. However, there are clusters which are so dense in their central sections that variable stars either cannot be detected there at all, or are only partially detected. Along with this, there are clusters which are completely resolved and studied (for example, NGC 5053, 5466, 6121, 6161).

The average distance from the cluster center up to the farthest third of the total number of stars of the RR Lyrae type in well resolved and studied clusters is used as the radius of the cluster. For less resolved and studied clusters, this fraction is increased somewhat, depending upon the extent to which it has been investigated. There is a certain arbitrary /63 element here, but it can be reduced after some practice.

The clusters in which the number of stars of the RR Lyrae type exceeded nine were selected. Not only stars whose periods were determined, but also all of the non-studied stars whose amplitudes and median apparent magnitudes corresponded to stars of the RR Lyrae type of a given cluster were employed.

All the diameters and radii of globular clusters in this book are given in logarithms of minutes of arc (lg d).

The following Table 6 gives the logarithms which we determined for the globular cluster diameters based on variable stars of the RR Lyrae type.

TABLE 6

NGC	$\lg d_{RR}$	NGC	$\lg d_{RR}$	NGC	$\lg d_{RR}$	NGC	$\lg d_{RR}$
2419	0.72	5272	1.12	6266	1.17	6715	1.13
3201	1.48	5466	1.03	6333	0.97	6723	0.85
4147	0.67	IC4499	0.93	6341	0.86	6934	0.75
4590	1.04	5824	0.99	6362	1.05	6981	0.70
4833	1.04	5904	1.15	6402	0.95	7006	0.64
5024	1.11	6121	1.32	6426	0.71	7078	1.03
5053	1.11	6171	0.97	6656	1.29	7089	1.15
5139	1.57	6229	0.62	6712	0.62		

With respect to the structural characteristics of globular clusters, the diameters derived on the basis of stars of the RR Lyrae type do not pertain to any specific section (nucleus, intermediate layer, corona). These values of the diameters were used only to take into account the influence of interstellar light absorption upon the cluster diameters measured by different methods. The weighted mean values (the weight was approximately determined from the deviations from the simple mean value) were obtained from all the diameter measurements thus corrected.

It was found during the reduction that the cluster diameters measured on the basis of star calculations, visual estimates, and photometric measurements are sensitive not only to interstellar absorption but also to atmospheric extinction. It was also found that the cluster diameters depend on the content of metals in the atmospheres of stars in these clusters. This dependence was less clearly expressed than the previous ones, but it was nevertheless real. It may be explained by the difference in the masses of blue stars on the horizontal branch and stars on the branch of the giants. Therefore, the diameters of clusters with a highly developed blue section on the horizontal branch may be much greater in the blue lines than in the red lines, and the diameters of clusters without a blue section on the horizontal branch may differ systematically, (B. V. Kukarkin, 1970). Terms /64 proportional to the atmospheric thickness and the metallicity index MI were included in the reduction formulas (see B. V. Kukarkin and R. M. Russev, 1972). A system based on the calculations of stars in 54 globular clusters was used as the system of diameters in this book (I. R. King, et al., 1968). The diameter corresponding to the intersection of the density logarithm function with the density of the background stars was used as the measured diameter of the cluster. To refine this quantity, the intersections were determined not only with the density logarithms of 0.0, but also

0.1 and 0.2 with respect to the background. The difference was found between these values and the value obtained for the equality with the background, after which the average of three determinations was taken and was used as the cluster radius. It was found that the radii obtained from the calculations of the stars were extremely sensitive both to interstellar and atmospheric absorption.

A comparison of the diameter system based on stellar calculations and designated by lg r (KHHW), with our preliminary system, which was previously described, led to the equation:

$$\begin{aligned} \lg d &= 0.04 + 1.05 \lg (\mathrm{KHHW}) + 0.97\,E(B-V) + 0.54z - 0.19\,\mathrm{IM}, \\ &\pm 0.11 \pm 0.07 \qquad\qquad \pm 0.14 \qquad\qquad \pm 0.15 \;\; \pm 0.24 \end{aligned} \tag{76}$$

where z— is the logarithm of the atmospheric thickness and MI— metallicity index. There is a clear dependence on light absorption in the interstellar medium and the atmosphere. The dependence on the metallicity index is poorly expressed for the simple reason that in the calculations of the stars the most informative material was used, but it was not uniform (photographs with different large instruments at different emulsions, with differing exposures, etc.).

As may be seen, it was found that the preliminary system was not too poor. Taking the fact into account that the proportionality coefficient between the systems (1.05) differs from unity within the limits of the mean square error, we did not correct our system.

All of the measurements were again reduced to this preliminary system, but with allowance for the terms z and MI.

It was found, during the first steps to formulate a uniform system of diameters, that the visual measurements of the diameters (for example, the first diameter system of Shapley-Sawyer) were not too poor, and, in terms of similarity with other determinations, sometimes even exceeded them in terms of accuracy. In this connection, and also due to the small amount of material for measuring diameters, and the absence of measurements for many globular clusters, particularly those discovered recently, the decision was made to make visual measurements in all the photographs and atlases available in the USSR.

The following sources were used: /65

KFA — Franklin-Adams Charts, London; 1914-1935. The diameters were determined only on maps of the first two volumes of the atlas (from the southern pole to +15° of the cluster).

KPA — National Geographical Society and Palomar Observatory Sky Survey, 1954 - 1966. The determinations were only made in order to select a method for obtaining only the mean value of measurements on maps obtained with the O and E emulsions. It was found that these measurements were comparable with other series in terms of accuracy.

KPAE — In the same atlas, the diameters were measured separately on maps obtained from photographs with the E emulsion.

KPAO — In the same atlas the diameters were measured separately on maps obtained from photographs with the O emulsion.

KLA — Lick Observatory Sky Atlas, 1967.

KVA2 — Vehrenberg, H., Atlas Stellarum, Düsseldorf, 1968-1970. In this atlas the measurements were only performed for reproduced plates obtained in the southern hemisphere.

KA — Measurements were made on numerous plates in the blue lines obtained between 1959 and 1973 at the southern station of the State Astronomical Institute in the Crimea by means of the Zeiss astrograph (400/1600 mm).

All of these measurements were reduced to the system which we selected. To save space, the reduction formulas were not given. Table 7 gives all of the measurements performed by means of the reduction formulas of the (76) type to our system. The corresponding columns at the end of the table give the mean square errors of measuring the diameter of one cluster.

All of the measurements of globular cluster diameters, which had already been published or were kindly given to me, were also reduced to our system. Brief information is also given on each of the measurement series and the reduction formulas are presented.

1. First measurements of H. Shapley and H. B. Sawyer, 1927b; H. Shapley, 1930 (SS1)

The visual measurements of globular cluster diameters in three different series of Harvard photographs of the sky as a whole form a rather uniform system. This is related with our system by the following formula:

$$\begin{array}{l} \lg d = 0.59 + 0.65\,(SS1) + 0.56\,E\,(B-V) - 0.14\,IM \\ \qquad\;\; \pm 0.04 \pm 0.03 \qquad\quad \pm 0.05 \qquad\qquad\quad \pm 0.08 \end{array} \qquad (77)$$

The mean square error of measuring one cluster is ± 0.08.

2. Microphotometric measurements of Shapley and Sayer (H. Shapley and A. R. Sayer, 1935). (SS2).

It is probable that the microphotometric measurements of the transverse sections of several globular clusters on different photographs of the Harvard collection were the first attempts at an instrument determination of the diameters. However, this /68
attempt at accuracy was not successful. The diameter system of Shapley-Sawyer was related with our system by the following

TABLE 7. DIAMETER MEASUREMENTS

NGC	KFA	KPA	KPAE	KPAO	KLA	KVA2	KA
104	1.49	–	–	–	–	1.52	–
288	1.12	1.26	1.18	1.18	1.03	0.96	–
362	1.14	–	–	–	–	0.19	–
1261	0.83	–	–	–	–	0.91	–
Pal 1	–	0.32	0.22	0.27	–	–	–
Pal 2	–	0.38	0.52	0.33	–	–	–
1851	1.06	–	1.11	–	–	0.98	–
1904	0.92	0.88	0.98	0.95	0.91	0.92	–
2298	0.97	–	0.77	–	–	0.84	–
2419	–	0.59	0.57	0.58	0.62	–	–
2808	1.15	–	–	–	0.80	1.27	–
Pal 3	–	0.54	0.40	0.48	–	–	–
3201	1.26	–	–	–	–	1.25	–
Pal 4	–	0.33	0.40	0.35	–	–	–
4147	0.63	0.56	0.65	0.65	0.65	–	–
4372	1.31	–	–	–	–	1.31	–
4590	0.98	1.08	1.07	1.15	1.09	1.04	–
4833	1.20	–	–	–	–	1.32	–
5024	1.16	1.14	1.15	1.13	1.02	–	1.11
5053	1.13	1.00	1.06	1.06	1.02	–	1.05
5139	1.61	–	–	–	–	1.61	–
5272	–	1.26	1.28	1.23	1.17	–	1.16
5286	1.05	–	–	–	–	1.08	–
5466	–	1.04	1.08	1.09	0.96	–	1.04
5634	0.58	0.76	0.68	0.73	0.66	0.70	0.73
5694	0.58	0.65	0.58	0.58	0.64	–	–
IC 4499	0.93	–	–	–	–	0.82	–
5824	0.79	0.74	0.79	0.79	0.87	0.87	–
Pal 5	–	0.92	0.81	0.83	–	–	–
5897	1.13	1.12	1.06	1.11	1.14	1.15	1.20
5904	1.16	1.30	1.29	1.24	1.28	–	1.24
5927	1.19	–	–	–	–	1.19	–
5946	0.85	–	–	–	–	1.06	–
5986	1.03	–	1.11	–	0.98	0.99	–
1609+15	–	0.47	0.34	0.27	–	–	–
6093	1.03	0.96	0.99	0.99	1.04	0.02	0.97
6101	1.08	–	–	–	–	1.09	–
6121	1.42	1.54	1.44	1.48	1.42	1.34	1.57
6139	0.77	–	0.91	–	–	0.93	–
6144	0.89	1.06	0.95	0.94	0.84	0.95	0.95
6171	1.08	1.12	0.98	1.00	0.94	–	1.00
6205	–	1.21	1.21	1.22	1.18	–	1.20
6218	1.23	1.21	1.20	1.18	1.19	–	1.09
6229	–	0.73	0.64	0.68	0.74	–	0.62
6235	0.71	0.73	0.69	0.67	0.72	0.82	0.75
6254	1.27	1.27	1.20	1.22	1.24	–	1.10
6266	1.20	1.22	1.35	1.28	1.31	1.22	1.00
6273	1.14	1.20	1.34	1.23	1.21	1.17	1.14
6284	0.83	0.76	0.79	0.80	0.81	0.89	0.83
6287	0.70	0.75	0.76	0.80	0.77	0.81	0.91
6293	1.09	0.94	0.97	0.95	1.00	0.97	0.93
6304	0.93	0.88	0.86	0.86	0.95	1.04	0.96
6316	0.72	0.80	0.84	0.74	0.77	0.86	0.85
6325	0.76	0.86	0.78	0.80	0.71	0.71	0.74
6333	1.11	1.00	1.01	1.03	1.07	1.13	1.04
6341	–	1.06	1.03	1.06	1.16	–	1.08
6342	0.63	0.52	0.56	0.47	0.43	0.72	0.65
6352	0.90	–	–	–	–	0.89	–

TABLE 7 (CONTINUED): DIAMETER MEASUREMENTS

NGC	KFA	KPA	KPAE	KPAO	KLA	KVA2	KA
6355	0.91	0.92	0.77	0.76	0.79	-	0.82
6356	0.90	0.82	0.85	0.87	0.83	0.98	0.85
Trz 2	-	-	0.37	0.30	-	-	-
6362	1.10	-	-	-	-	1.17	-
6366	0.89	1.06	1.06	1.07	1.02	-	-
Trz 4	-	-	0.26	-	-	-	-
HP 1	-	-	0.66	0.67	-	-	-
6380	-	-	0.76	-	-	0.56	-
6388	1.06	-	0.97	-	-	1.00	-
Trz 1	-	-	0.84	-	-	-	-
Ton 2	-	-	0.63	-	-	-	-
6397	1.51	-	-	-	-	1.36	-
6401	0.84	0.98	0.92	0.85	0.70	0.92	0.82
6402	1.19	1.14	1.12	1.17	1.20	-	1.11
Pal 6	-	1.28	1.06	1.24	-	-	-
6426	0.53	0.47	0.51	0.52	0.60	-	0.65
Trz 5	-	-	0.87:	-	-	-	-
6440	0.91	0.96	0.85	0.96	0.94	0.97	1.00
6441	0.98	-	1.07	-	0.97	0.95	-
Trz 6	-	-	0.25	-	-	-	-
6453	0.70	-	0.67	-	0.84	0.39	-
6496	0.84	-	0.80	-	-	-	-
6517	0.79	0.80	0.80	0.81	0.73	-	0.91
6522	0.92	0.78	0.86	0.85	0.93	0.96	-
6528	0.68	0.67	0.72	0.70	0.84	0.69	-
6535	0.66	0.51	0.59	0.64	0.47	-	0.82
6539	1.04	1.04	0.95	0.96	0.97	-	1.01
6541	1.18	-	1.12	-	-	1.17	-
6544	1.16	1.05	1.08	1.06	1.11	1.05	-
6553	0.92	1.09	1.07	1.18	0.97	0.93	-
6558	0.65	0.60	0.61	0.65	0.71	0.67	-
IC 1276	-	0.97	0.95	0.95	-	-	-
6569	0.83	0.81	0.90	0.84	0.83	0.78	-
6584	0.88	-	-	-	-	0.94	-
6624	0.86	0.79	0.80	0.82	0.87	0.82	-
6626	1.13	1.13	1.11	1.16	1.13	1.16	1.01
6637	0.98	0.84	0.85	0.87	0.90	0.87	-
6638	0.83	0.77	0.73	0.79	0.81	0.75	0.75
6642	0.91	0.72	0.65	0.70	0.75	0.75	0.65
6652	0.65	-	0.60	-	0.67	0.71	-
6656	1.55	1.50	1.44	1.42	1.54	1.46	1.51
Pal 8	-	0.66	0.68	0.69	-	0.78	-
6681	0.86	0.95	0.91	0.95	0.89	0.87	-
6712	0.99	0.89	0.95	0.96	0.94	-	0.82
6715	1.09	0.94	0.98	0.99	0.96	0.91	-
6717	-	0.61	0.62	0.69	-	-	-
6723	1.06	-	1.06	-	0.97	1.06	-
6749	-	0.93	0.91	1.03	-	-	-
6752	1.26	-	-	-	-	1.32	-
6760	1.13	0.93	0.96	0.99	0.88	-	0.97
6779	-	0.82	0.91	0.89	0.97	-	0.84
Pal 10	-	0.62	0.62	0.65	-	-	-
1927-30	-	0.70	0.63	0.53	-	-	-
6809	1.32	1.28	1.33	1.28	1.30	1.18	-
Pal 11	-	0.64	0.54	0.52	-	-	-
6838	0.96	0.86	0.91	0.83	0.97	-	0.91
6864	0.81	0.75	0.81	0.81	0.75	0.89	-
6934	0.88	0.74	0.75	0.76	0.74	-	0.78
6981	0.76	0.66	0.72	0.73	0.81	-	0.87
7006	0.48	0.37	0.46	0.46	0.59	-	0.45
7078	1.02	1.05	1.11	1.09	1.18	-	1.11
7089	1.10	1.05	1.10	1.10	1.14	-	1.08
7099	0.99	1.02	1.06	1.05	1.06	1.00	1.09
Pal 12	-	0.38	0.41	0.53	-	-	-
Pal 13	-	0.30	0.28	0.22	-	-	-
7492	0.92	0.73	0.78	0.78	0.74	-	0.96
σ	±0.07	±0.06	±0.05	±0.04	±0.07	±0.08	±0.08

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relationship:

$$\lg D = 0.09 + 0.84\,(SS2) + 0.27\,E\,(B-V) - 0.06\,IM \qquad (78)$$
$$\pm 0.07 \pm 0.04 \qquad \pm 0.09 \qquad \pm 0.11$$

The mean square error of measuring one cluster is ± 0.09.

As may be seen from the coefficients in Formula (78), the microphotometric method of measuring diameters is less sensitive to the absorption of light than visual measurements, particularly less sensitive than calculations of stars.

3. Photometric measurements of diameters by Mowbray in the blue and red lines (A. G. Mowbray, 1946) (MB,MR).

Out of all the globular cluster diameter measurements which we used, the measurements of Mowbray are the most accurate. This may probably be explained by the rigorous selection of uniform observational material. The diameters of Mowbray are related with our system by the following equations:

$$\lg d = 0.15 + 0.83\,(MB) + 0.67\,E\,(B-V) + 0.37z - 0.14\,IM \qquad (79)$$
$$\pm 0.04 \pm 0.03 \qquad \pm 0.04 \qquad \pm 0.04 \quad \pm 0.06$$

$$\lg d = 0.41 + 0.73\,(MR) + 0.45\,E\,(B-V) + 0.23z - 0.20\,IM \qquad (80)$$
$$\pm 0.04 \pm 0.02 \qquad \pm 0.06 \qquad \pm 0.05 \quad \pm 0.09$$

The mean square errors of measuring one cluster are ± 0.05 and ± 0.035, respectively.

A study of the coefficients is very instructive in the case of the sequential terms of Equations (79) and (80). First of all, it is apparent that the "red" diameters are longer than the "blue" diameters (ratio of the coefficients 1.1). This may probably be explained by the fact that in the red photographs the integral effect of the weak red dwarfs of the main sequence, whose masses are small and whose sub-system is more extended, becomes apparent. It is natural that the interstellar absorption of light has much greater influence upon the "blue" diameters than upon the "red" diameters (ratio of the coefficients is 1.5). Naturally, atmospheric extinction has a greater influence upon the "blue" diameters than upon the "red" diameters (ratio of the coefficients is 1.6). In the case of the metallicity index, the coefficient for the "blue" diameters is less than for the "red" diameters. This also has a natural explanation, if it is assumed that the masses of the blue stars of the horizontal branch are less than the masses of the red stars on the branch of the sub-giants with luminosities which are most effective in this range of absolute stellar magnitudes.

4. Visual measurements of new globular clusters of G. O. Abell, 1955 (Pal)

It was at first difficult to obtain a reduction formula for the Abell measurements, since it is impossible to compare his measurements with others. However, after the reduction of our measurements (see Table 7) this was done: /69

$$\begin{array}{l} \lg d = 0.07 + 0.71\,(\mathrm{Pal}) + 0.46\,E\,(B-V) + 0.52\,z \\ \qquad\ \pm 0.05 \pm 0.08 \qquad\quad \pm 0.04 \qquad\qquad \pm 0.23 \end{array} \tag{81}$$

The mean square error of measuring the diameter of one cluster is ± 0.06.

5. Photometric measurements of the diameters of Kron and Mayall (G. E. Kron and N. U. Mayall, 1960) (KM)

The cluster diameter for which the luminosity was 0.9 of the entire flux in the V photometric system was used as the diameter of Kron and Mayall. The Kron and Mayall system of diameters was related with our system by the following equation:

$$\begin{array}{l} \lg d = 0.32 + 0.84\,(\mathrm{KM}) - 0.05\,E\,(B-V) + 0.19\,z - 0.28\,\mathrm{IM} \\ \qquad\ \pm 0.09 \pm 0.07 \qquad\quad \pm 0.08 \qquad\qquad \pm 0.10 \ \ \pm 0.14 \end{array} \tag{82}$$

The mean square error of measuring the diameter of one cluster is ± 0.11.

As may be seen from the coefficients, the Kron-Mayall system of diameters was less sensitive both to interstellar and atmospheric absorption, but it was very sensitive to the metallicity of the clusters. This may probably be explained by the fact that the equipment used was more sensitive to the blue region of the spectrum and the diameters of the clusters with heavily populated blue ends of the horizontal branches were systematically larger due to the relatively small masses of the stars.

6. Diameters based on the determinations of Kinman and Rosino (T. D. Kinman and L. Rosino, 1962) (KR).

Kinman and Rosino calculated the stars in seven poorly studied globular clusters and published the corresponding tables. The weighted average for the densities of 0.2 and 0.1 (weights of 2 and 1, respectively) was used as the diameter. The small number of clusters measured made the reduction formula very unreliable, which is confirmed by the great errors of the coefficients:

$$\begin{array}{l} \lg d = 0.18 + 0.68\,(KR) + 0.25\,E\,(B-V) + 0.53z \\ \quad\;\; \pm 0.11 \pm 0.12 \qquad\;\; \pm 0.23 \qquad\qquad\;\; \pm 0.64 \end{array} \qquad (83)$$

The mean square error of measuring the diameter of one cluster is ± 0.10.

7. Determination of the diameters based on the calculations of stars (I. R. King, E. Hedemann, S. M. Hodge, R. F. White, 1968) (KHHW).

The system of the authors enumerated in the heading was used for formulating our system. Nevertheless, after calculating /70 the weighted averages of all the determinations, we obtained a reduction formula which was very similar to Formula (76). The mean square error of determining the diameter of one cluster was ± 0.14. Thus, the diameters determined from the calculations of the stars were found to be least accurate. The reason for this can apparently be found in the very great sensitivity of these determinations to interstellar and atmospheric absorption. It is also very probable that the estimate of the diameter depends on the richness of the stellar background. Allowance for this effect requires the development of a special method, and we simply did not have the time to solve this problem.

6. Diameters based on stars of the RR Lyrae type.

Just as in the preceding case, the diameters for stars of the RR Lyrae type were used to formulate our system of globular cluster diameters. Nevertheless, it is interesting to compare the diameter system with the weighted average values obtained from all the determinations. In actuality, as a result of reducing and averaging individual determinations having random and systematic errors which were not taken into account, it was possible to accumulate deviations acting in one direction. Therefore, the values on Table 6 were again compared with the weighted average values of the diameters obtained from all the determinations described above. It was found that the effect of interstellar reddening did not equal zero, which may probably be explained by a certain overestimation of this factor in the reduction formulas. All of the apparent diameters were reduced according to the formula

$$\lg d_0 = \lg d - 0.18\,E(B-V) \qquad (84)$$
$$\pm 0.10$$

9. Diameters based on electronographic observations of G. E. Kron, 1973 (Kr)

Kron kindly put at our disposal his electronographic measurements of diameters and integral stellar magnitudes of 14 globular star clusters. He measured diameters corresponding to 0.1, 0.5 and 0.9 of the entire flux of the cluster emission. We compared the diameters corresponding to 0.9 with the diameters in our system. They are related by the formula (obtained graphically):

$$\lg d = 0.02 + 1.365 \lg d\ (\mathrm{Kr}\ 0.9)$$

The mean square error of measuring the diameter of one cluster is ± 0.12.

10. Diameters of H. Wilkens, 1970.

Since the diameter system of Wilkens is based on the microphotometric measurements of Shapley and Sawyer (H. Shapley, et al., 1935) and on the diameters for stars of the RR Lyrae type, we cannot assume that his system is independent of ours. Both of these series of measurements were used in our system. Therefore, the diameters of Wilkens were not used. /71

As was noted previously, the very valuable studies of I. R. King, 1974, were obtained so late that they could make no substantial contribution to the development of our system of globular cluster diameters. We believe that our system must be similar (or proportional) to the system of limiting radii of King. To verify this, we graphically compared our final diameters with the logarithms of the limiting radii of King. As may be seen (see Figure 5) both systems have a linear inter-relationship.

The following equation was obtained graphically:

$$\lg(RT) = 0.28 + 0.94 \lg d_0 \qquad (86)$$

Thus, the rich material from our determinations of globular cluster diameters can be used in the King system of limiting radii.

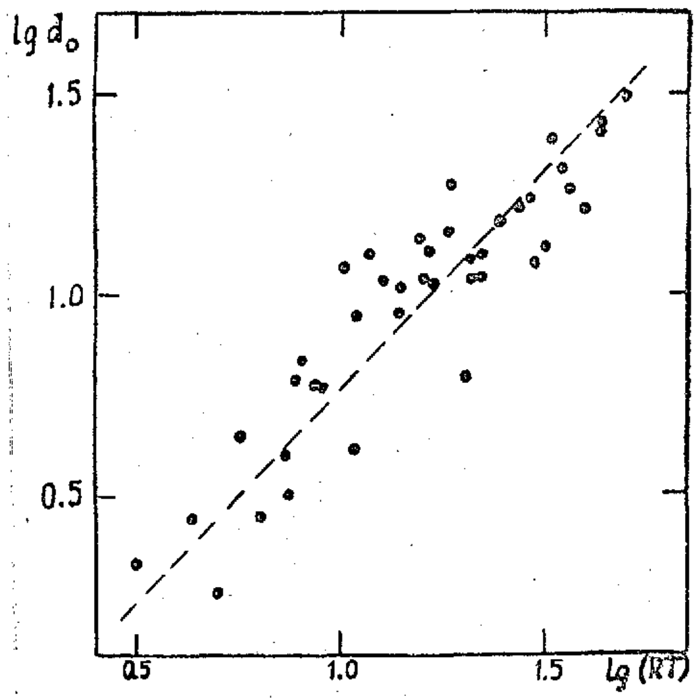

Figure 5. Dependence between the logarithms of apparent diameters of globular clusters in our system and the limiting radii of King lg(RT)

Certain formulas for reducing diameters to a uniform system /72
include the value of MI. This may be explained by the fact that the formulas were calculated before the new calibration of the metal content, which was performed comparatively recently. The following relationship holds between the values [m/H] and MI (B. V. Kukarkin, 1973).

$$\begin{array}{ll} [m/H] = 4.4\,\mathrm{IM} - 2.88 & \mathrm{IM} > 0.45 \\ [m/H] = 6.4\,\mathrm{IM} - 3.77 & \mathrm{IM} < 0.45 \end{array} \qquad (86a)$$

The values which we derived for the diameters of globular clusters are given in Table E. They are expressed in logarithms of minute of arc. Just as in the preceding cases, a unit of weight corresponds to the mean square error of ±0.10. /73

8. MODULI OF GLOBULAR CLUSTER DISTANCES

The determination of the moduli of globular cluster distances, just like the measurement of their diameters, were placed on the solid ground of facts after the classical work of H. Shapley. We shall not discuss the history of this problem, since it is very well covered in the monograph of Shapley himself (H. Shapley, 1930), and several other studies.

For the almost 30 years since Shapley, the basic method of determining the apparent moduli of globular cluster distances has been the variable stars of the RR Lyrae type. This was particularly convenient, since Shapley had given them an absolute median magnitude of 0.00. Thus, it was sufficient to determine the apparent magnitude of stars of the RR Lyrae type in a given globular cluster. Their apparent magnitude corresponded to the apparent modulus of the distance.

However, after the "catastrophe" with the zero-point of the "period-luminosity" dependence of the classical cepheids, which was followed in 1952 in connection with the significant studies of W. Baade, 1954, there was a more careful study of the problem of the absolute magnitudes of stars of the RR Lyrae type.

E. D. Pavlovskaya first showed that these stars are weaker than was assumed. In addition, he was the first to point to significant dispersion of the absolute magnitudes of stars of the RR Lyrae type (E. D. Pavlovskaya, 1953). From that time on, the problem of the absolute magnitudes of stars of the RR Lyrae type became the subject of numerous studies, devoted to determinations of the eigen movements and radial velocities, as well as to pure theoretical determinations. Our problem will not include them. We would only like to note that there is no doubt that the absolute magnitude of stars of the RR Lyrae type in globular clusters is between $+0^m.5$ to $+1^m.2$ and that the dispersion of the absolute magnitudes of even a given cluster is real, without even considering the dispersion during the transition from one cluster to another (we are not referring to the problem of the dwarf cepheids and other pulsating stars which have still not been discovered in the globular clusters).

A quarter of a century ago, S. A. Zhevakin began studies which placed solid ground under the theory of stellar pulsation and gave an impetus to modeling of pulsating stars (S. A. Zhevakin, 1947, 1952, 1963, 1970).

Later Christy developed the ideas of Zhevakin, constructed a model and developed certain theoretical premises (R. F. Christy, 1962; 1964; 1966; 1970). Other important studies were published on the pulsation theory, but our problem will not include their analysis.

One of the promising relationships following from the studies of Christy was the dependence between the luminosity of stars of the RR Lyrae type and the so-called transition period P_{tr} (see page 60). We assume this dependence has the following formula:

$$M_V^{RR} = -0.58 - 4.46 \lg P_{tr} \qquad (87)$$ /74

Only after many hesitations and tests did we use the absolute magnitudes calculated according to this formula as the basis for calibrating a system of absolute magnitudes of other stars, the sequences and points on the color-luminosity diagrams of globular clusters. Information in this regard is given on pages 58-61. We would only like to add that numerous studies of recent years absolutely indicate the necessity of a certain small additional attenuation of luminosity of stars of the RR Lyrae type in globular clusters. These studies also substantiate the considerable dispersion of their values both within each cluster and, in particular, in the transition from one cluster to another. Equation (87) fully satisfies both of these patterns.

After discovering a clearly expressed dependence of the absolute magnitudes of stars of the RR Lyrae type, calculated from Formula (87), on the content of metals [m/H] and the integral spectrum Sp (see Table D at the end of the book), we obtained the preliminary average values of all three determinations. After this, we again solved the equations relating the quantities [m/H] and Sp with the absolute magnitudes of stars of the RR Lyrae type. As a result, the following formulas were obtained for calculating the absolute magnitudes of stars of the RR Lyrae type:

$$M_V^{RR} = \underset{\pm 0.02}{1.32} + \underset{\pm 0.01}{0.38}\,[m/H] \tag{88}$$

$$M_V^{RR} = \underset{\pm 0.027}{0.425} + \underset{\pm 0.04}{0.60}\,(Sp - F0.0) \tag{89}$$

These formulas were used to obtain new numerical values of the absolute magnitudes of stars of the RR Lyrae type in the V system, and these values were again averaged with the values obtained directly from Formula (87). Thus, weights were used which were calculated based on the deviations from the overall average and with allowance for the reliability of determining P_{tr}, [m/H] and Sp.

Table 8 gives the absolute magnitudes of stars of the RR Lyrae type which we used (and, consequently, absolute magnitudes of the horizontal branches of those clusters for which such calculations were possible).

The unit of weight formally corresponds to the mean square error of ±0.10, but the real error of the absolute magnitude is much greater.

TABLE 8 /75

NGC	M_V^{RR}	Wt	NGC	M_V^{RR}	Wt	NGC	M_V^{RR}	Wt
104	1.14	8	6121	0.90	8	IC 1276	0.68	2
288	0.80	4	6139	1.03	5	6553	1.24	8
362	0.93	8	6171	1.01	10	6569	1.02	2
1261	0.86	4	6205	0.74	14	6584	1.00	5
1851	0.91	5	6218	0.75	8	6624	1.21	4
1904	0.75	7	6229	0.84	9	6626	0.94	9
2298	0.79	5	6254	0.78	12	6637	1.27	10
2419	0.72	6	6266	0.94	10	6638	1.08	5
2808	0.81	6	6273	0.83	13	6642	1.00	5
3201	0.84	8	6284	0.86	6	6652	1.09	5
Pal 4	0.88	1	6293	0.67	6	6656	0.65	13
4147	0.72	9	6304	1.33	6	6681	0.84	7
4372	0.69	4	6316	0.99	2	6712	0.98	10
4590	0.58	7	6333	0.65	7	6715	0.85	8
4833	0.62	4	6341	0.56	17	6723	1.04	8
5024	0.66	16	6352	1.24	4	6752	0.75	7
5053	0.58	6	6356	1.24	14	6760	1.06	4
5139	0.70	11	6362	0.91	6	6779	0.66	12
5272	0.82	17	6388	1.23	6	6809	0.68	7
5466	0.63	6	6397	0.75	7	6838	1.16	11
5634	0.75	3	6402	0.88	12	6864	0.88	10
5694	0.69	4	6426	0.69	3	6934	0.80	8
5824	0.61	6	6440	1.26	7	6981	0.84	7
Pal 5	0.9:	½	6441	1.25	6	7006	0.73	11
5897	0.58	6	6522	0.98	8	7078	0.57	19
5904	0.83	17	6528	1.30	5	7089	0.68	17
5927	1.29	6	6535	0.89	1	7099	0.58	11
5946	0.73	2	6539	1.30	½	Pal 13	0.85	1
5986	0.81	8	6541	0.72	6	7492	0.82	2
6093	0.78	8	6544	0.97	2			

1. Determination of apparent modulii of distances based on stars of the RR Lyrae type and the horizontal branch

In 1974 we had at our disposal 78 color-luminosity diagrams of 47 globular clusters. We are referring only to those diameters which were formulated either directly in the U,B,V,I photometric systems or in other systems which could be more readily reduced. Several diagrams were placed at our disposal during the study.

Table 8 gives a fairly reliable absolute value of V of stars of the RR Lyrae type (which corresponds to the horizontal branch) for all 47 globular clusters. Table 3 gives the magnitudes of stars on the horizontal branch (HB) also in the V system measured according to the color-luminosity diagrams. Variable stars of the RR Lyrae type in the 47 globular clusters were studied to a certain extent. In some of the clusters, their apparent magnitudes were determined directly in the B and V systems. For the majority of the clusters, only the photographic values in the old international system are known. When there were color-luminosity diagrams in the B,V systems for such clusters, using the comparison stars it was usually easy to change from the published values to values in the B system. In the remaining cases (not reduced directly), reduction to the B system was performed according to the formula:

$$B = m_{pg} + 0\overset{m}{.}10, \ (m_{pg} < 14\overset{m}{.}0); \qquad (90)$$
$$B = m_{pg} + 0\overset{m}{.}1(m_{pg} - 14\overset{m}{.}0) + 0\overset{m}{.}1, \ (m_{pg} > 14.0)$$

The value of $[+0.26 + E(B-V)]$ was subtracted from the median value of B thus obtained, where +0.26 was assumed to be the true mean value (B-V) for stars of the RR Lyrae type (i.e., free from interstellar absorption). Table 9 gives the median values V of stars of the RR Lyrae type. In those cases when the magnitude was obtained from Formulas (90), it is given in parentheses in Table 9. The fact must be kept in mind that median values are given in Table 9. This was done intentionally, since there is no possibility of calculating the average values of V based on intensity for several clusters. The weight of the median apparent magnitudes was calculated based on the deviations from the average values in such a way that the unit of weight corresponded to the mean square error of ±0.10.

Combining the apparent magnitudes of stars on the horizontal branch from Table 3 and the apparent magnitudes of stars of the RR Lyrae type from Table 9 with the absolute magnitudes from Table 8, we obtain the preliminary values of the distance moduli Mod^{RR}_{app} и Mod^{HB}_{app}. These moduli values were used to calibrate all of the remaining methods of determining the globular cluster distances. / 77

TABLE 9

NGC	m_V	Wt	NGC	m_V	Wt	NGC	m_V	Wt
362	(15.51)	0.7	Pal 5	17.35	1.1	IC1276	(18.57)	0.6
1261	16.60	1.6	5897	16.23	2.2	6558	(16.71)	0.6
1904	(16.31)	0.4	5904	15.02	9.5	6626	(15.83)	0.6
2419	(19.61)	1.3	5986	(16.43)	0.3	6656	(13.89)	1.0
2808	16.86	0.5	6093	(15.82)	0.3	6712	16.16	3.0
3201	14.80	4.6	6121	13.29	3.2	6715	(17.10)	1.8
4147	16.80	2.0	6171	15.60	4.5	6723	15.53	4.7
4590	(15.80)	1.5	6205	14.72	2.0	6934	16.93	2.7
4833	(15.33)	0.7	6229	(17.65)	1.0	6981	16.94	5.1
5024	16.88	5.9	6266	(16.32)	2.2	7006	18.81	6.0
5053	16.24	1.6	6333	(16.15)	0.8	7078	15.83	8.3
5139	14.51	11.4	6341	15.11	3.5	7089	15.97	4.1
5272	15.59	13.7	6362	(14.72)	0.9	7099	15.11	1.7
5466	16.58	4.5	6402	17.31	1.5	Pal 13	17.70	2.0
5634	(16.98)	0.6	6426	(17.72)	0.8	7492	17.08	1.7
5824	(17.72)	1.2	6522	(16.40)	0.3			

2. Determination of apparent distance moduli based on 5 and 25 of the brightest stars in globular clusters

For a long time the old method of Shapley has been disregarded. This method is based on estimates of stellar magnitudes of 25 of the brightest stars in the globular clusters. An attempt was made to reestablish this method by H. Arp, 1965. In a recent study (B. V. Kukarkin and R. M. Russev, 1972), it was shown that this method leads to very encouraging results when there is a more rigorous selection of the cluster stars. All of the magnitudes published in the study just mentioned were carefully compiled and corrected. A short time after this investigation was completed, many studies were published or placed at our disposal which made it possible to expand and refine the preliminary data.

For our purposes of using the bright stars in determining the apparent distance moduli, we selected only stars on the branch of the giants-sub giants. The cepheids and other possible members of the clusters (see, for example R. J. Zinn, et al., 1972) were naturally excluded from the examination.

The brightest stars on the branch of the giants in the color-luminosity diagram are located on its uppermost right end. This portion of the branch is almost parallel to the abscissa axis. Thus, these stars are particularly suitable for determining the distance moduli. In the case of 25 stars, the situation is somewhat more complex, since these stars are located on the steeper /78
section of the branch of the giants changing into the branch of the sub-giants. Disregarding stars in the dense sections of the clusters may lead to the result that the average of the apparent magnitudes of 25 bright stars is less than the true value. It is true that the average based on five of the brightest stars is not guaranteed to escape this effect.

Studies of limited value, which were recently performed (Z. I. Kadla, 1971; Z. I. Kadla, S. Spasova, 1972), make it possible to not only qualitatively examine this problem. Using instruments with a large focal distance, Z. Kadla was able to measure photometrically stars in the dense central sections of several of the clusters which have been well studied. It is particularly important that Kadla determined the eigen movements of these stars; this made it possible to distinguish the stars on the background with great reliability. We shall not further discuss the promising conclusions of Kadla and Spasova regarding the structural characteristics of the brightest stars (strong concentration toward the center!) which are very important for solving the problem of the relative masses of globular star clusters pertaining to different sequences on the color-luminosity diagrams. We shall simply compare their results and our determinations of the magnitudes of five of the brightest stars.

NGC	5272	5904	6205	6341
Kadla and Spasova	12.41	11.81	12.03	11.94
Kukerkin	12.64	12.29	12.03	12.12
C (King, 1974)	1.90	1.78	1.55	1.78
M_V	−8.4	−8.3	−8.2	−7.9

Identical material was probably used in the case of NGC 6205. In the three remaining cases, we could not take into account the stars in the central regions. Apparently, the brightest stars of the massive clusters are actually located in the most central regions. Naturally taking them into consideration unavoidably leads to distortion of the V5, V25, B5, B25 magnitudes. However, the concentration of stars and a great amount of stars in the clusters is closely related with the masses, and consequently with the integral luminosities (absolute magnitudes) of the clusters. Thus the "non-solvability" of the central cluster regions (and consequently the systematic error in the V5, V25, B5, B25 magnitudes) will increase with an increase in M_V^{cl}. This magnitude is included

TABLE 10

NGC	V5	V25	B5	B25	NGC	V5	V25	B5	B25
104	11.62	11.92	13.03	13.38	6341	12.12	12.52	13.44	13.67
362	12.66	13.14	14.32	14.64	6352	13.06	13.77	14.93	15.42
1261	13.60	14.44	15.04	16.66	6356	15.01	15.29	17.00	17.27
Pal 2	17.5:	–	19.7:	–	6362	12.05	13.21	14.24	14.63
1851	13.31	13.88	15.02	15.29	6397	10.16	10.96	11.65	12.16
2298	13.68	14.56	14.96	15.63	6402	14.39	14.88	16.57	16.76
2808	13.20	13.62	15.03	15.34	6522	13.64	14.68	15.54	16.37
3201	11.96	12.73	13.60	14.07	6528	15.05	–	17.28	–
Pal 4	17.78	18.91	19.26	19.93	6541	12.30	12.90	13.81	14.10
4147	14.85	15.75	15.94	16.67	6637	13.07	13.64	15.18	15.52
4372	12.25	13.04	14.01	14.54	6656	10.96	11.59	12.94	13.28
4833	12.41	12.91	14.10	14.41	6712	13.65	14.42	15.45	16.06
5024	13.90	14.54	15.38	15.73	6723	13.10	13.85	14.70	15.14
5053	13.94	14.91	15.12	15.82	6752	10.98	11.72	12.49	12.90
5139	11.52	11.78	12.98	13.23	6779	13.24	14.19	14.81	15.34
5272	12.64	13.27	14.20	14.55	6838	12.40	13.24	14.24	14.74
5466	13.69	14.39	14.98	15.45	6934	14.16	15.01	15.57	16.20
5897	13.42	14.28	14.97	15.48	6981	14.53	15.12	15.75	16.21
5904	12.29	12.82	13.75	14.11	7006	15.89	16.60	17.41	17.84
6121	19.93	11.67	12.75	13.11	7078	12.83	13.62	14.06	14.56
6171	13.22	13.85	15.11	15.46	7089	13.26	13.78	14.58	14.89
6205	12.03	12.48	13.45	13.79	7099	12.45	13.35	13.73	14.31
6218	12.25	13.20	13.70	14.38	7492	14.81	15.74	16.19	16.74
6254	11.96	12.71	13.63	14.14					

in an equation such as (91). Thus, the coefficients for the term M_V^{cl} in equations (92-95) will significantly compensate for the error arising due to not taking into account (or partially taking into account) stars in the central regions of the globular clusters. The distance moduli obtained from these formulas closely coincide with independent determinations, which serve as the best confirmation of our statements. / 79

Unfortunately Kadla and Spasova did not publish the (B-V) magnitudes of the bright stars in the central regions of the clusters which they studied. Therefore, we cannot establish the position of these stars on the color-luminosity diagram. We hope that they will continue to study the giants in the clockwise direction. If they form a special family of objects, this will be no less interesting.

Table 10 gives the V5, V25, B5 and B25 values which we used for 49 globular clusters (they are very exact for two clusters). It is extremely difficult to determine the errors in these quantities, since, contrary to custom, we did not take any weights, and we assume that they are approximately of equal value, excluding two cases noted with a colon.

Taking the fact into account that all the bright stars have low temperatures and TiO absorption bands are formed in their atmospheres, which are particularly numerous in the V photometric system and less numerous in the B system, it may be assumed that the moduli determined from the values of B5 and B25 will be more precise than the moduli determined from the values V5 and V25. /80

With an increase in the content of metals in stellar atmospheres, the bolometric corrections will rapidly increase, and along with that the B-V values will increase. Due to this, the branch of the giants will become more and more sloping (there are other reasons for this phenomenon, related to the internal structure of these stars). Therefore, it is necessary to introduce a term into the reduction equations which depends on the content of metals [m/H]. In addition, it is apparent that the more stars there are in a cluster, the brighter will be the stars in a cluster of high luminosity, due to the greater population of the branch of the giants. Consequently, it is necessary to include a term in the reduction formulas which is proportional to the richness of the luminosity function. A good substitute for such a quantity may be the absolute magnitude of globular clusters. This method was put into practice (B. V. Kukarkin, R. M. Russev, 1972) and gave very good results. Just as in the study mentioned, equations of

C-2

the following form were formulated

$$\mathrm{Mod}_{app} = V5 + a + b\,[m/H] + cM_V^{CI} \tag{91}$$

and solved by the method of least squares. As a result, the following four formulas were obtained:

$$\begin{aligned}\mathrm{Mod}^V_{app} &= V5 + \underset{\pm 0.20}{0.03} - \underset{\pm 0.06}{0.52}\,[m/H] - \underset{\pm 0.03}{0.15}\,M_V^{CI} && (92)\\ \mathrm{Mod}^V_{app} &= V25 - \underset{\pm 0.28}{1.46} - \underset{\pm 0.09}{0.33}\,[m/H] - \underset{\pm 0.04}{0.30}\,M_V^{CI} && (93)\\ \mathrm{Mod}^B_{app} &= B5 - \underset{\pm 0.11}{1.36} - \underset{\pm 0.04}{0.77}\,[m/H] - \underset{\pm 0.02}{0.12}\,M_B^{CI} && (94)\\ \mathrm{Mod}^B_{app} &= B25 - \underset{\pm 0.16}{2.24} - \underset{\pm 0.06}{0.66}\,[m/H] - \underset{\pm 0.02}{0.20}\,M_B^{CI} && (95)\end{aligned}$$

Our qualitative predictions regarding the expected relative accuracy of each of the equations were confirmed: the smallest error in determining the apparent distance modulus of one cluster ±0.10 was obtained for magnitudes based on the values of B5. Then B25 follows (error ±0.15), V5 (error ±0.16) and V25 (error ±0.24).

As was already noted above, Shapley continued to determine the distances up to the globular clusters, using the magnitudes of the bright stars. He published the photographic magnitudes of 25 of the brightest stars, and also the magnitudes of stars of the sixth and thirtieth order of brightness in each of the 48 globular clusters (H. Shapley, 1930). In some subsequent books and summaries of Shapley himself, as well as other authors, the data on the mean photographic magnitude of 25 of the brightest stars was repeated, expanded, and somewhat changed. We should recall the very valuable catalog of globular clusters of Sawyer and Hogg, which included the magnitudes for 66 clusters (H. B. Sawyer-Hogg, 1963). Two years later Arp reduced the photographic magnitudes of 25 bright stars by means of formulas (90) to the /81
B system, and reduced the number of clusters to 67 (H. Arp, 1965).

It was shown recently that the magnitude of Arp contains a systematic error related to the galactic latitude (B. V. Kukarkin, R. M. Russev, 1972). It would probably be more correct to search for the cause of the systematic error in the color excess E (B-V), but — taking into consideration the low accuracy of the magnitudes of Arp — we did not continue this study, so as not to delay publication of this book. In correcting the magnitude of Arp for the "effect of galactic latitude", we obtained the following formula, connecting the corrected magnitudes of Arp (B'25) with the apparent distance moduli in our system:

$$\mathrm{Mod}^{B}_{app} = (B'25) - \underset{\pm 0.41}{2.98} - \underset{\pm 0.13}{0.61}\,[m/H] - \underset{\pm 0.06}{0.36}\,M_B \tag{95a}$$

The mean square error of determining the distance modulus of one cluster was ±0.35, which was much worse than any of the determinations used in formulas (92) - (95). Nevertheless, it is necessary to use these moduli, especially when there are no more reliable determinations. The mean weight of these determinations is naturally not large (0.08).

In calculating the apparent moduli based on equations (92) - (95a) we must always keep the fact in mind that it is necessary to solve these equations with successive approximations, assuming preliminary M_V and M_B values which are as close as possible to the desired values. Two approximations are usually necessary. It is necessary to make a greater number of approximations in the case of an unsuccessful selection of the preliminary value of the absolute magnitude.

Visual determinations of the magnitudes of bright stars of van den Bergh and the $(m-M)_V$ values derived by him may also be used. They were reduced to our system using the following formula:

$$\mathrm{Mod}^{V}_{app} = 6.00 + \underset{\pm 0.09}{0.82}\,(m-M)_V - \underset{\pm 0.17}{0.72}\,[m/H] \tag{95b}$$

The mean square error of determining the distance modulus of one cluster was very large and was ±0.46. The mean weight of these determinations was 0.05 in all.

3. Determination of the apparent moduli of globular clusters based on the cepheids.

At present (1974) about 40 variable stars of the cepheid and RV Taurus type have been discovered in globular clusters. Apparently, serious attention was first given to their similarity with variable stars of the W Virgo type in 1950 (B. V. Kukarkin and P. G. Kulikovskiy, 1951).

Unfortunately, too little attention has recently been given to a study of variable stars of this type in globular clusters (in contrast to red variable stars). This may be due to the fact that primary interest was attached to stars of the RR Lyrae type in studying the variable stars in globular clusters. /82

Fortunately in recent years cepheids in globular clusters have finally attracted their merited attention. After the interesting sporadic study of H. C. Arp, 1955a, only a few individual studies appeared. S. Demers recently continued the group of studies (see, for example, S. Demers, 1971), but his studies are based on a very small number of observations. The problem was raised of finding cepheids in globular clusters (G. Wallerstein, 1970), and also attempts were made to determine their location in stellar evolution (see, for example, M. Schwarzschild and R. Härm, 1970). Many other authors have pointed out the unusual period-luminosity relationship in stars of the W Virgo type (see, for example, M. S. Frolov, 1970; K. K. Kwee, 1968).

In 1971, A. S. Rastorgouev became interested in the problem of cepheids in globular clusters. He used the rich collection of photographs of globular clusters accumulated since 1959 at the

State Astronomical Institute Imeni P. K. Shternberg in Moscow. Based on his preliminary results, Rastorgouev formulated anew the period-luminosity relationship for cepheids in globular clusters (B. V. Kukarkin and A. S. Rastorgouev, 1972; 1973). This relationship, which was calibrated based on the absolute magnitudes of stars in the horizontal branch given in the study of Kukarkin and Russev (B. V. Kukarkin and R. M. Russev, 1972), is well approximated by the following two linear equations:

$$\left.\begin{array}{ll} M_V = -0.26 - 1.12 \log P & (\log P < 1.13) \\ \quad \pm 0.07 \pm 0.08 & \\ M_V = +2.66 - 3.89 \log P & (\log P > 1.13) \\ \quad \pm 0.10 \pm 0.11 & \end{array}\right\} \tag{96}$$

$$\left.\begin{array}{ll} M_B = -0.08 - 0.70 \log P & (\log P < 1.13) \\ \quad \pm 0.06 \pm 0.07 & \\ M_B = +3.61 + 4.11 \log P & (\log P > 1.13) \\ \quad \pm 0.09 \pm 0.08 & \end{array}\right\} \tag{97}$$

These formulas are tentative in nature. At the present time A. S. Rastorgouev has concluded the study of all the cepheids in globular clusters, for which it was important to obtain reliable data. We did not wish to delay the completion of our book, since it is already assumed that the new formulas will differ from the previous formulas (96) and (97) so slightly that they will not have a significant influence upon the apparent distance moduli of globular clusters derived in this book.

Utilizing formulas (96) and (97) and the apparent magnitudes of cepheids in globular clusters, the apparent distance moduli were calculated. Weights were given to them which were not established rigorously but, as far as possible, in such a way that the unit of weight, just as in other cases, corresponded to the mean square error of ±0.10 in the modulus value. /83

Photoelectric measurements of cepheids in globular clusters in different frequency ranges are very desirable. There are practically no such measurements (the few observations cannot be used as material for reliable statistical processing).

It is known that in dwarf galaxies of the stellar system type in the clusters Sculptor and Draco variable stars are encountered with periods from 0.45 to 1.6 days and with absolute magnitudes which are approximately one stellar magnitude higher as compared with the magnitude of stars on the horizontal branch (W. Baade, H. Swope, 1961; S. van Agt, 1967; H. Swope, 1968; P. N. Kholopov, 1971; S. van Agt, 1973).

If we assume that the absolute stellar magnitude M_B equals $+ 1^m.0$ for stars of the RR Lyrae type in these stellar systems, the luminosity-period relationship may be represented by the equation:

$$M_B = -0.22 - 1.88 \log P \qquad (98)$$

However, we must approach this problem with great caution. A simple examination of the histograms for periods of type RR Lyrae stars in the dwarf galaxies (S. van Agt, 1973), undoubtedly indicates the unusual population of these stellar systems. Only one histogram for the system in Sculptor has a great similarity with the histogram for the globular cluster M3. In all the remaining cases, it is impossible to find a good analog among the globular clusters of our galaxy. It is impossible to attribute an identical content of metals for all stars in the dwarf galaxies and a relatively identical time of formation for the stars populating them.

Variable increased luminosities are also encountered in the globular clusters of our galaxy. For example, these are the stars V9 in the cluster 47 Tuc, stars V3, V31 in cluster NGC 6402, stars V19 in cluster NGC 6712, and stars V16, V21 in cluster 6723. All of these clusters have a relatively high content of metal.

However, are not all of these stars variable stars at differing stages of development than stars of the RR Lyrae and W Virgo type?

We have attempted to illustrate in one figure the period-luminosity dependence for stars of the RR Lyrae type, stars of increased luminosity in the dwarf galaxies, cepheids in the globular clusters of our galaxy, and the initial portion of the dependence for classical cepheids. It must be recalled that the absolute magnitudes of stars of the RR Lyrae type were assumed to equal ($+1^{m}.0$) for all dwarf galaxies. It is probable that this is not the case, and therefore stars of higher luminosity may be rearranged on the figure.

Apparently, we must not now assume that there is a real difference between cepheids in the globular clusters of our galaxy and stars of increased luminosity in dwarf galaxies. /84

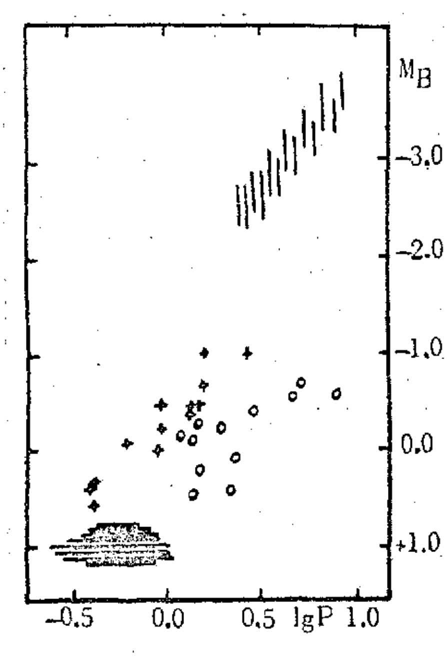

Figure 6. Period-luminosity dependence (in absolute stellar magnitudes B) for different types of periodic pulsating stars. The horizontal dashed lines show the region of stars of the RR Lyrae type. Stars of increased luminosity in different dwarf galaxies are designated by the crosses. The cepheids in globular clusters of our galaxy are shown by circles, and the vertical lines designate the beginning of the classical cepheid region.

It is possible that these variable stars are at identical stages of development and the dispersion in their values may be related (apart from observation errors) with a difference in chemical composition and mass with other characteristics.

It is necessary to continue the studies of variable stars in all the available dwarf galaxies. The galaxy in Sculptor is particularly interesting, i.e., it includes cepheids and possibly red variables, apart from more than 600 variables of the RR Lyrae type.

4, 5, 6. Determination of the distance moduli of globular clusters based on red variable stars of different types.

Unfortunately, red variable stars, just like stars of the W Virgo type, were not of interest for a long period of time to researchers of globular clusters. This is particularly surprising, since even in 1955 M. Walker formulated the assumption that in globular clusters all red giants which are brighter than a certain value are variable stars (M. F. Walker, 1955). However, no one was interested in this and the problem was not considered until the 1970's (R. M. Russev, 1971; O. J. Eggen, 1972). It was found that in selected coordinate systems the red variable stars are definitely localized on the color-luminosity diagrams.

Starting at the end of the 1960's, more and more frequently studies appeared devoted to an investigation of red variable stars in globular clusters. Apart from the practical importance of their study (for example, the possibility of determining distances) investigations into the theory of stellar evolution (see, for example, K. Schwarzschild, 1970) played an important role in the emerging interest in these stars. It follows from these studies that nonstationary phenomena may be characteristic for stars /85
localized on the upper right end of the branch of the giants.

These stars may be in a stage of great qualitative reorganization.

Since three special reviews (M. F. Feast, 1972, 1973; T. Lloyd Evans, 1973) were recently devoted to the problem of the red variable stars in globular clusters, we shall not go into detail on these general problems, particularly since they have already been partially covered (see pages 90-93). Let us now examine three possible methods of determining the apparent distant moduli for the red stars.

A. Red irregular and semi-regular stars-giants are primarily encountered in clusters of high metallicity, although they are found in clusters with a low content of metals. The problem of observing these stars in clusters is very complex and requires the most accurate possible approach. This, in its turn, is connected with the selection of a good coordinate system for the color-luminosity diagrams. The photometric system V and the color equivalents B-V are absolutely unsuitable for a scientifically valid classification of red variable stars in globular clusters (even in the galactic field).

Attempts are now being made to find a practical solution to this problem. It is sufficient to examine the study of O. Eggen (see, for example, O. J. Eggen, 1972 and previous studies of the same author mentioned there). A single glance at the diagram of Lloyd Evans (T. Lloyd Evans, 1973) is sufficient to establish that, with an appropriate selection of the coordinates, red variable stars are localized in terms of luminosity hardly more precisely than stars of the RR Lyrae type. This is due to the fact that the V coordinate was replaced by the I_K coordinate. If Lloyd Evans had replaced the V-I coordinates, the picture would be much more clear.

First of all, an attempt was made to connect the apparent magnitudes of the red variable stars in the I_K photometric system with the apparent distant moduli Mod^{IK}_{app}. Eleven conditional equations were formulated whose solution led to the following relationship:

$$Mod^{IK}_{app} = \underset{\pm 0.06}{3.60 + 0.97}\,Ik - \underset{\pm 0.10}{0.13}\,[m/H] \qquad (99)$$

The attempt was successful. In spite of the relatively small amount of material, the mean square error of determining the apparent distance moduli of one cluster was ±0.18, which is comparable with other methods of average reliability. When reliable I_K values of red variable stars are determined for all 25 globular clusters, where variable stars of this type have already been found, and when searches are made for those variable stars in other clusters, this method of determining the distances will probably be found to be one of the most reliable. It is /86
apparent that it is not necessary to stop with the I_K photometric system. Other systems may be selected.

B. The mean apparent magnitudes of irregular and semi-regular variable stars in 22 globular clusters were compared with the distance moduli in our system Mod^{B}_{app}. All of these quantities were reduced to the B photometric system. As a result, the following formula was obtained:

$$Mod^{B}_{app} = -0.84 + \underset{\pm 0.04}{1.02}\,B - \underset{\pm 0.12}{0.76}\,[m/H] \qquad (100)$$

The mean square error of determining the apparent distance modulus of one cluster was found to be ±0.29. With a more accurate and more numerous series of observations of red variable stars in photometric system B, this error is reduced and this method of determining the distances is suitable and sufficiently accurate.

C. It was recently shown that variable stars of the Mira Cetus type are encountered in globular clusters with a high metal content. By 1974, a little more than ten stars of the Mira Cetus type were known, and there was no doubt that they belonged to clusters (for the majority of the stars, the radial velocity was measured, which was found to be close to the velocities of the clusters themselves). Unfortunately, the result was quite unsatisfactory with photometric observations of the stars. There is no assurance that the published photographic magnitudes at the maximum pertained to the maximum of the average altitude (as is known, the maximum photographic magnitudes of a given star of the Mira Cetus type are not the same). There are no systematic observations in photometric systems which are good for studying red stars. Some stars of the Mira Cetus type have not been studied at all.

In spite of the sparse material, it has been possible to obtain the maximum values in a system close to B for seven stars of the Mira Cetus type in four globular clusters. A comparison of these values with the apparent distance moduli in our Mod^V_{app} system led to the following formula:

$$\mathrm{Mod}^V_{app} = \mathrm{Max}_B \underset{\pm 0.14}{-0.20} \underset{\pm 0.27}{-2.76}[m/H] \qquad (101)$$

The mean square error of determining the apparent distance modulus of one cluster is ±0.14. This was undoubtedly due to the small number of equations. If there had been three of them, the solution would be absolutely accurate. However, in general, this method of determining the distance to the globular clusters merits attention.

The methods described above for determining the apparent distance moduli of globular clusters for red stars are very promising. However, there is material which is absolutely not suitable for a detailed study of the problem. Further observations are necessary, if possible in frequency ranges (B, I_J, I_K, 104) which are suitable for stars with molecular spectra, as well as the selection of suitable color equivalents which are unequivocally connected with temperature. /87

It was shown in one of our studies that the so-called concentration classes of Shapley-Sawyer are correlated much better with the absolute magnitudes of globular clusters than with any magnitudes or qualitative classes which actually characterize the concentration of stars in globular clusters (B. V. Kukarkin, 1971). Actually, it is sufficient to examine Figure 4 (page 62) to see that there is an uncertain connection between the concentration classes of Shapley-Sawyer and the quantity "C" (I. R. King, 1974).

Since the publication of our study on the concentration classes of globular clusters (B. V. Kukarkin, 1971), additional methods were found for determining the "richness" of globular clusters with stars.

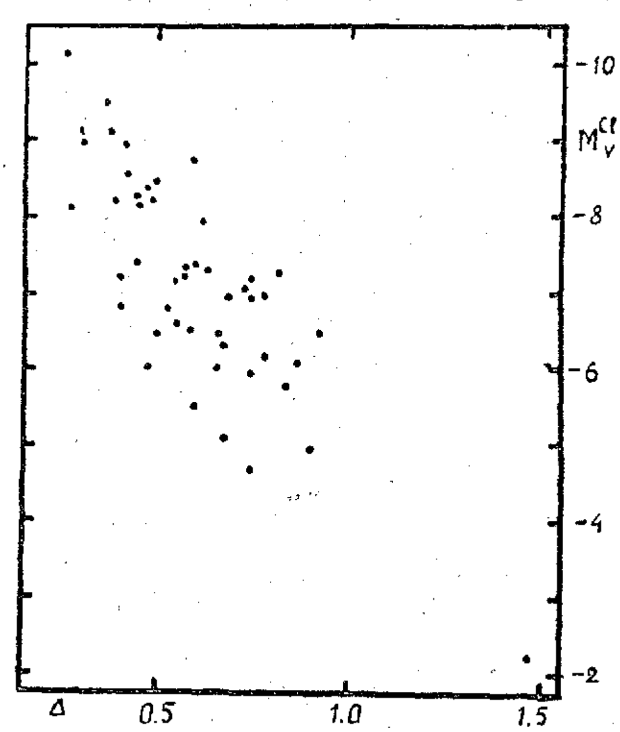

Figure 7. Dependence between the integral absolute stellar magnitude of globular clusters and the quantity $\Delta = \frac{1}{2}[(V25-V5)+(B25-B5)]$

TABLE 11

NGC	IR	Wt	NGC	IR	Wt	NGC	IR	Wt
104	0.75	3.3	6218	0.42	4.0	6535	0.24	3.0
288	0.30	3.2	6229	0.69	3.3	6539	0.31	3.5
362	0.66	3.3	6235	0.35	3.3	6541	0.56	3.6
1261	0.47	3.5	6254	0.49	4.2	6544	0.47	2.6
Pal 1	0.11	2.2	6266	0.67	4.0	6553	0.42	3.3
Pal 2	0.33	2.4	6273	0.61	3.7	6558	0.53	2.6
1851	0.64	3.7	6284	0.58	3.6	IC1276	0.18	2.2
1904	0.61	3.2	6287	0.43	3.8	6569	0.45	3.5
2298	0.40	3.6	6293	0.63	3.6	6584	0.60	3.2
2419	0.64	3.3	6304	0.67	3.5	6624	0.62	3.5
2808	0.76	3.0	6316	0.58	3.5	6626	0.66	3.6
Pal 3	0.10	2.4	6325	0.41	3.5	6637	0.59	4.2
3201	0.39	2.8	6333	0.56	3.7	6638	0.68	3.5
Pal 4	0.17	2.8	6341	0.61	4.0	6642	0.58	3.0
4147	0.39	4.1	6342	0.65	3.5	6652	0.70	3.2
4372	0.26	2.6	6352	0.35	3.5	6656	0.56	4.4
4590	0.45	3.5	6355	0.42	3.0	Pal 8	0.37	2.2
4833	0.55	3.3	6356	0.69	4.2	6681	0.57	3.5
5024	0.61	4.2	Trz 2	0.45:	1.0	6712	0.44	4.6
5053	0.18	4.2	6362	0.42	3.2	6715	0.68	3.5
5139	0.86	3.3	6366	0.16	3.5	6717	0.47	2.2
5272	0.64	4.2	Trz 4	0.6:	1.0	6723	0.53	4.0
5286	0.71	2.4	HP 1	0.24	2.0	6749	0.28	3.3
5466	0.27	4.4	6380	0.34	1.7	6752	0.56	3.3
5634	0.56	3.6	6388	0.64	2.8	6760	0.42	3.5
5694	0.64	3.2	Trz 1	0.40	1.4	6779	0.43	4.5
IC4499	0.17	2.2	Ton 2	0.23	1.7	Pal 10	0.11	2.2
5824	0.72	3.5	6397	0.37	3.3	1925–30	0.06	2.0
Pal 5	0.08	2.4	6401	0.49	3.0	6809	0.38	3.3
5897	0.32	4.5	6402	0.65	4.5	Pal 11	0.17	2.2
5904	0.62	4.4	Pal 6	0.26	2.2	6838	0.29	4.0
5927	0.58	2.4	6426	0.29	3.6	6864	0.72	3.2
5946	0.53	2.2	Trz 5	0.8:	1.0	6934	0.55	4.2
5986	0.62	3.3	6440	0.54	3.3	6981	0.46	4.4
1608+15	0.08	1.7	6441	0.79	3.2	7006	0.51	4.6
6093	0.72	3.7	Trz 6	0.3:	1.0	7078	0.64	4.4
6101	0.29	2.0	6453	0.70	2.8	7089	0.71	4.6
6121	0.38	4.0	6496	0.21	2.4	7099	0.47	4.4
6139	0.60	2.4	6517	0.89	3.8	Pal 12	0.13	2.2
6144	0.27	3.3	6522	0.60	3.7	Pal 13	0.02	2.4
6171	0.39	4.2	6528	0.49	3.3	7492	0.18	4.1
6205	0.70	4.4						

One of the most suitable quantities characterizing the /90
population of the luminosity function of the given globular cluster is the difference between the apparent stellar magnitudes of five and twenty-five stars V25-V4 and V25-B5 (see Table 10). The following value of Δ was proposed:

$$\Delta = \frac{1}{2}\left[(V25 - V5) + (B25 - B5)\right] \tag{102}$$

This quantity proved to have a very reliable correlation with the absolute magnitudes M_V of globular clusters (see Figure 7).

Table 11 on page 101 gives the richness index IR. This was obtained as a result of further reduction of all additional determinations to the scale selected previously.

A comparison of the richness indices with the most reliable determinations of the absolute magnitudes M_V and M_B of 42 globular clusters made it possible to obtain the following two formulas:

$$M_V = \underset{\pm 0.28}{-3.49} - \underset{\pm 0.51}{7.31}\ \mathrm{IR} \tag{103}$$

$$M_B = \underset{\pm 0.30}{-2.91} - \underset{\pm 0.56}{7.17}\ \mathrm{IR} \tag{104}$$

The mean square errors of determining the absolute magnitude of one cluster are ±0.52 and ±0.56, respectively.

As may be seen, this method of determining the absolute magnitudes of globular clusters is one of the least accurate methods. Nevertheless, in certain cases a knowledge of the richness index is one of the few possibilities of determining the distance to a globular cluster. This is important for clusters which are not well studied.

Determination of true distance moduli of globular clusters based on their diameters

The chapter of the book devoted to determination of the diameters of globular clusters showed that the system selected is practically free of the influence of light absorption. This makes the diameters of globular clusters suitable for determining the true distance moduli.

Preliminary values of the true distance moduli were obtained by subtracting the tripled value E (B-V) from the apparent modulus $\mathrm{Mod}^{V}_{app.}$ Forty-seven globular clusters were selected, for which both the true distance moduli and the diameters were determined very unreliable. It is apparent that the true cluster diameter must be related with its mass. The cluster mass may be replaced by the integral absolute magnitude M_V. In addition, as was already noted above, the content of metals may also introduce a systematic error into any system of determining the diameters. Actually in /91 globular clusters with a high metal content there are practically no white or blue stars on the horizontal branch. If the masses of the red and blue stars are different and this difference existed for a rather long period of time with respect to the time of relaxation, then in measurements of the diameters at different wavelengths we will make differing determinations of the influence upon the diameter of blue and red stars. In the red lines, the influence of blue and white stars will be attenuated, whereas in the blue lines, it will be intensified. Finally, it follows from the theoretical calculations of the dynamic evolution of globular clusters that the limiting radius must greatly depend on the distance of the given cluster from the center, particularly from the galactic plane.

When an empirical formula was selected for representing the apparent diameter of globular clusters as an index of the distance, it was decided to represent the true modulus Mod_0 as a function of the logarithm of the globular cluster diameter lg d, its absolute magnitude M_V, the metal content [m/H], and the logarithm of the z-coordinate of the cluster (in terms of the modulus):

$$\mathrm{Mod}_0 = a + b \lg d + c M_V + d[m/H] + \lg z \qquad (105)$$

As a result of solving 47 arbitrary equations by the method of least squares, the following formula was obtained:

$$\begin{array}{llllll} \mathrm{Mod}_0 = 15.17 & - 3.52 \lg d & - 0.26 M_V & - 0.28 [m/H] & + 1.52 \lg z & (106) \\ & \pm 0.32 & \pm 0.05 & \pm 0.14 & \pm 0.13 & \end{array}$$

The mean square error of determining the true distance modulus of one globular cluster based on formulas (106) is ±0.39. This is a low accuracy, but frequently the cluster diameter is the only numerical characteristic, which may be used to obtain the approximate distance to the cluster.

The proposed method for determining the true distance moduli of globular clusters based on the apparent diameters, reduced to our system which is free of the influence of interstellar absorption of light, is not sufficiently accurate and is comparable with the most reliable methods of determining the distances. Nevertheless, it was suitable for determining the distances of globular clusters. This is very important in the case of those clusters for which other methods cannot be used. The complexity of formulas (105) requires a skillful selection of the necessary parameters and the successive approximations when solving the equation. However, our experience has shown that with practice and a certain amount of intuition the disadvantage of this method can be overcome.

Rectangular coordinates of globular clusters

For all of the globular clusters whose distance from the Sun is given in Table F, formulas (1), (2) and (3) were used to calculate the rectangular coordinates x, y, z. The x axis is directed from the Sun to the center of the galaxy; the y axis is directed from the Sun to a point on the galactic equator with a longitude of 90°; the z axis is directed toward the North Pole of the galactic coordinate system.

The rectangular coordinates thus calculated are given in a supplementary table after Table F. The fact must be kept in mind that, in the case of calculations using the distances from Table F, small divergences from the values of the supplementary table may be encountered. This may be explained by the fact that the values in Table F were rounded off as a function of the accuracy of determining the distances. In the supplementary table, calculated by means of a computer, the initial data were not rounded off and formally contained the number of signs assigned by the computer.

Radial velocities of globular clusters

The supplementary table also gives the radial velocities of globular clusters. All of the measurements of radial velocities of globular clusters and individual stars in the clusters published before 1974 were re-examined. The Mayall and Kinman system of radial velocities was used (N. U. Mayall, 1946); (T. D. Kinman, 1959a). The last of these studies used all of the published measurements of radial velocities.

After the publication of the study of Kinman, numerous determinations were published of the radial velocities of individual stars in several clusters (M. W. Feast, et al, 1960; Fehrenbach, C. et al., 1962; R.v.d.R. Woolley, 1966; M. W. Feast, 1967; R. M. Catchpole et al., 1970; M. W. Feast, 1972;

P. J. Andrews, et al., 1974) and the integral radial velocities of 22 globular clusters (S. van den Bergh, 1969). These latter determinations needed a systematic correction of +19 km/sec (the same value was derived in the study of van den Bergh but with a different sign; this is probably an oversight).

Based on the deviations of individual determinations from the preliminary weighted averages, the mean errors of all the series of observations used were redetermined and new values of the weights were calculated. In the majority of cases, they were proportional to the weights used in the book of Kinman.

The values used for the mean radial velocities of globular clusters and their weights are given in the last two columns of the supplementary table. The unit of weight corresponds to the mean square error of ±10 km/sec.

P A R T 2

GENERAL CATALOG OF GLOBULAR CLUSTERS OF OUR GALAXY

Description of the general catalog of globular clusters in our galaxy. /99

All of the general characteristics of globular clusters in our galaxy, reduced to a uniform system (see the first part), are given in six tables, designated by the letters A,B,C,D,E,F.

Table A

This table gives the names and locations of globular clusters in the celestial sphere. The table contains the following columns:

1. Name of globular cluster based on the NGC catalog and, when this catalog does not give it, the name is given from another, most widely used source. A second name is given after the first, if it is found in the literature.
2. Right ascension and declination for the 1950 equinox.
3. Annual precession for the 1950 equinox.
4. Galactic coordinates in the new system (position of the mean galactic pole R.A.= 12^h49^m; Dekl. = +27°.4 (1950)).

Table B

Table B contains auxiliary quantities which may be useful when studying the three-dimensional distribution of globular clusters or investigating their kinematics. The table contains the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2. Cosine of the galactic longitude cos l.
3. Sine of the galactic longitude sin l.
4. Cosine of the galactic latitude cos b.

5. Sine of the galactic latitude sin b.
6. Product sinl cosb.
7. Product cosl cosb.
8. Cosecant of galactic latitude |csc b|.

Table C.

Table C gives information on the photometric characteristics of globular clusters and their color excesses reduced to a uniform system. This information is given for each cluster on two pages. The left page contains the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2. Integral stellar magnitude of the cluster V. /100
3. Weight of this quantity.
4. Sources given at the end of the table and in a general summary at the end of the book.
5. Color equivalent (B-V).
6. Weight of this quantity.
7. Sources indicated at the end of the table and in the general summary at the end of the book.

The right page includes the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2. Color equivalent (U-B).
3. Weight of this quantity.
4. Sources given at the end of table and in the general summary at the end of the book.
5. Color equivalent (V-I).
6. Weight of this quantity.
7. Sources given at the end of the table and in the general summary at the end of the book.
8. Color excess E(B-V).

9. Weight of this quantity.

A list of sources used in deriving all of these quantities is given at the end of the table. The complete bibliographic information is given at the end of the book.

Table D.

Table D contains information on the integral spectral classes of clusters and the content of metals reduced to a uniform system. The table contains the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2. Integral spectral class of the globular cluster. When the spectral class is derived only on the basis of photometric measurements, its value is given in parentheses.
3. Weight of determining the spectral class.
4. Sources used in determining the spectral class given at the end of the table and in the general summary at the end of the book.
5. Quantity [m/H] characterizing the metal content in the atmospheres of the cluster stars. It corresponds to the logarithm of the metal content with respect to the Sun.
6. Weight of the quantity [m/H].
7. Sources used to determine this quantity given at the end of the table and in the general summary at the end of the book.

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Table E.

Table E contains information on the diameters and apparent distance moduli of clusters reduced to a uniform system. The table contains the following columns.

1. Name of the cluster in accordance with the first name in Table A.
2. Logarithm of the cluster diameter expressed in minutes of arc lg d.
3. Weight of this quantity.
4. Sources used to determine the diameters given at the end of the table and in the summary at the end of the book.
5. Apparent distant moduli Mod^{V}_{app}.
6. Weight of these quantities.
7. Methods used in determining the apparent distance moduli. They are given at the end of the table.

When using this table, the fact must be kept in mind that both the diameters and the distance moduli must be regarded as tentative, although they are given in a uniform system. Both the problem of measuring the diameters and the problem of determining the distance scales are very complex and will be repeatedly re-examined.

Table F.

Table F repeats (sometimes in a somewhat changed form), without the details, the weights, sources, and all of the data regarding globular clusters obtained in a uniform system. The information contained in Tables A and B is not repeated.

The purpose of this table is to provide a convenient reference source for those individuals not interested in problems related to the study of globular clusters, but who need the information. Just as in Table C, the information about the clusters in Table F is given on two consecutive pages. The left side contains the following information:

1. Name of the cluster in accordance with the first name in Table A.
2. Integral magnitude of cluster V.
3. Color equivalent B-V.
4. Color equivalent U-B.
5. Color equivalent V-I.
6. Spectral class of the cluster. The parentheses indicate that the spectral class was only derived on the basis of photometric measurements.
7. The quantity [m/H] designating the logarithm of the metal content with respect to the Sun.
8. Repetition of Column 1 for convenience in using the table.

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The right page contains the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2. Color excess E (B-V).
3. True distance modulus Mod_0^V.
4. Distance of the cluster from the Sun corresponding to this modulus, given in kiloparsecs.
5. Cluster diameter logarithm expressed in minutes of arc.
6. Linear cluster diameter in parsecs.
7. Absolute magnitude of the globular cluster.
8. Repetition of Column 1 for convenience in using the table.

Supplementary table

This table gives the rectangular coordinates of globular clusters. The origin is at the center of the Sun. The x axis is directed toward the center of the galaxy; the y axis — toward a point on the galactic equator with 90° longitude; the z axis — toward the North Pole of the galactic coordinate system. The table contains the following columns:

1. Name of the cluster in accordance with the first name in Table A.
2, 3, 4. Rectangular coordinates x,y,z in kiloparsecs.
5. Radial velocity of the cluster VR.
6. Weight (unit of weight corresponds to the mean error of ±10 km/sec).

The mean error of any value for the quantities whose weights are given in Tables C, D and E may be calculated according to the formula

$$\text{m.e.} = \frac{\pm 0.10}{\sqrt{\text{Wt}}}$$

in units of the quantity itself.

TABLE A. COORDINATES OF GLOBULAR CLUSTERS

Cluster		R.A. (1950)	Decl. (1950)	Prec. (1950) R.A.	Prec. (1950) Decl.	l	b
104	47 Tuc	$00^h21.^m8$	$-72°21'$	$+2.^s68$	$+0.'333$	$305.^\circ90$	$-44.^\circ90$
288		50. 2	-26 52	+2.93	+0.326	149.67	-89.40
362	Δ 62	01 01. 6	-71 07	+2.04	+0.322	301.52	-46.26
1261		03 10. 9	-55 25	+1.63	+0.225	270.56	-52.12
Pal 1		25. 7	+79 28	+8.68	+0.208	130.02	+19.06
Pal 2		04 43. 1	+31 23	+3.84	+0.110	170.49	-08.98
1851	Δ 508	05 12. 4	-40 05	+1.97	+0.069	244.49	-35.04
1904	M 79	22. 2	-24 33	+2.47	+0.055	227.22	-29.33
2298		06 47. 2	-35 57	+2.13	-0.068	245.63	-16.01
2419		07 34. 8	+39 00	+4.06	-0.134	180.37	+25.25
2808		09 10. 9	-64 39	+1.12	-0.247	282.18	-11.26
Pal 3		10 03. 0	+00 18	+3.08	-0.292	240.26	+41.86
3201	Δ 445	15. 5	-46 09	+2.48	-0.300	277.21	+08.64
Pal 4		11 26. 6	+29 16	+3.18	-0.331	202.31	+71.80
4147		12 07. 6	+18 49	+3.06	-0.334	252.89	+77.19
4372		23. 0	-72 24	+3.48	-0.332	301.01	-09.90
4590	M 68	36. 8	-26 29	+3.18	-0.330	299.62	+36.04
4833		56. 0	-70 36	+3.99	-0.324	303.59	-08.01
5024	M 53	13 10. 5	+18 26	+2.94	-0.318	333.00	+79.76
5053		13. 9	+17 57	+2.94	-0.317	335.56	+78.95
5139	ω Cen	23. 8	-47 13	+3.58	-0.312	309.10	+14.97
5272	M 3	39. 9	+28 38	+2.77	-0.303	042.24	+78.70
5286	Δ 388	43. 0	-51 07	+3.79	-0.301	311.57	+10.58
5466		14 03. 2	+28 46	+2.70	-0.287	042.13	+73.59
5634		27. 0	-05 45	+3.15	-0.268	342.22	+49.26
5694		36. 7	-26 19	+3.49	-0.259	331.06	+30.36
IC4499		× 52. 7	-82 02	+9.60	-0.244	307.36	-20.50
5824		15 00. 9	-32 53	+3.69	-0.235	332.55	+22.06
Pal 5		13. 5	+00 05	+3.07	-0.222	000.85	+45.86
5897		14. 5	-20 50	+3.44	-0.221	342.94	+30.29
5904	M 5	16. 0	+02 16	+3.03	-0.219	003.86	+46.80
5927		24. 4	-50 29	+4.33	-0.210	326.62	+04.87
5946		31. 8	-50 30	+4.37	-0.201	327.28	+04.19
5986	Δ 552	42. 8	-37 37	+3.92	-0.188	337.01	+13.28
1608+15	Pal 14	16 08. 8	+15 05	+2.75	-0.156	028.76	+42.16
6093	M 80	14. 1	-22 52	+3.58	-0.149	352.67	+19.45
6101		20. 0	-72 06	+6.81	-0.141	317.73	-15.83
6121	M 4	20. 6	-26 24	+3.68	-0.140	350.99	+15.96
6139		24. 3	-38 44	+4.05	-0.136	342.37	+06.94
6144		24. 2	-25 56	+3.67	-0.136	351.92	+15.68
6171	(M 107)	29. 7	-12 57	+3.38	-0.128	003.37	+23.02
6205	M 13	39.9	+36 33	+2.14	-0.114	059.00	+40.91
6218	M 12	44. 6	-01 52	+3.11	-0.108	015.70	+26.32
6229		45. 6	+47 37	+1.69	-0.107	073.64	+40.30
6235		50. 4	-22 06	+3.59	-0.100	358.91	+13.52

Cluster		R.A. (1950)	Decl. (1950)	Preac. (1950) R.A.	Preac. (1950) Decl.	l	b
6254	M 10	$16^h54.^m5$	$-04°02'$	$+3.^s16$	$-0.'094$	015°.13	+23°.07
6256	Trz 12	56.0	−37 00	+4.04	−0.092	347.81	+03.36
Pal 15		57.6	−00 28	+3.08	−0.089	018.89	+24.27
6266	M 62	58.1	−30 03	+3.82	−0.089	353.58	+07.30
6273	M 19	59.5	−26 12	+3.71	−0.087	356.86	+09.39
6284		17 01.5	−24 41	+3.67	−0.084	358.37	+09.93
6287		02.1	−22 38	+3.61	−0.084	000.13	+11.04
6293		07.1	−26 30	+3.72	−0.076	357.64	+07.84
6304		11.4	−29 24	+3.81	−0.070	355.84	+05.37
6316		13.4	−28 05	+3.77	−0.067	357.17	+05.78
6325		15.0	−23 42	+3.65	−0.065	000.93	+08.00
6333	M 9	16.2	−18 28	+3.51	−0.063	005.53	+10.72
6341	M 92	15.6	+43 11	+1.84	−0.064	068.35	+34.86
6342		18.2	−19 32	+3.54	−0.061	004.90	+09.73
6352		21.6	−48 25	+4.67	−0.056	341.38	−07.18
6355		20.9	−26 19	+3.72	−0.057	359.58	+05.42
6356		20.7	−17 46	+3.52	−0.057	006.73	+10.21
Trz 2	HP 3	24.3	−30 46	+3.86	−0.052	356.31	+02.30
6362	Δ 225	26.6	−67 01	+6.19	−0.049	325.54	−17.56
6366		25.1	−05 02	+3.19	−0.051	018.42	+16 03
Trz 4	HP 4	27.4	−31 33	+3.89	−0.047	356.03	+01.31
HP 1		27.9	−29 57	+3.84	−0.047	357.42	+02.11
6380	Ton 1	32.0	−39 02	+4.15	−0.041	350.31	−03.58
6388		32.6	−44 43	+4.39	−0.040	345.54	−06.74
Trz 1	HP 2	32.6	−30 26	+3.85	−0.040	357.57	+01.00
Ton 2		32.7	−38 31	+4.13	−0.040	350.80	−03.41
6397		36.8	−53 39	+4.88	−0.034	338.18	−11.98
6401		35.5	−23 53	+3.66	−0.035	003.45	+03.97
6402	M 14	35.0	−03 14	+3.17	−0.036	021.31	+14.79
Pal 6		40.6	−26 12	+3.73	−0.028	002.09	+01.78
6426		42.4	+03 12	+3.01	−0.026	028.09	+16.24
Trz 5	Trz 11	45.0	−24 46	+3.69	−0.022	003.84	+01.69
6440		45.9	−20 21	+3.57	−0.021	007.72	+03.80
6441		46.8	−37 02	+4.08	−0.019	353.53	−05.00
Trz 6	HP 5	47.5	−31 16	+3.88	−0.018	358.56	−02.16
6453		48.0	−34 37	+4.00	−0.017	355.74	−03.97
6496		55.5	−44 14	+4.37	−0.007	348.06	−10.01
Trz 9		58.7	−26 52	+3.75	−0.002	003.60	−02.04
6517		59.1	−08 57	+3.28	−0.001	019.23	+06.77
6522		18 00.4	−30 02	+3.85	+0.001	001.03	−03.93
6528		01.6	−30 04	+3.85	+0.002	001.13	−04.17
6535		01.3	−00 18	+3.08	+0.002	027.18	+10.43
6539		02.1	−07 35	+3.28	+0.003	020.80	+06.78
6541	Δ 473	04.4	−43 44	+4.35	+0.006	349.27	−11.19
6544		04.3	−25 01	+3.70	+0.006	005.83	−02.22

ORIGINAL PAGE IS
OF POOR QUALITY

TABLE A. COORDINATES OF GLOBULAR CLUSTERS (CONTINUED) /108

Cluster		R.A. (1950)	Decl. (1950)	Preac. (1950) R.A.	Preac. (1950) Decl.	l	b
6553		$18^h06^m.3$	$-25°56$	$+3^s.72$	$+0'.009$	$005°.25$	$-03°.06$
6558		07.0	−31 47	+3.90	+0.010	000.20	−06.03
IC1276	Pal 7	08.0	−07 14	+3.24	+0.012	021.82	+05.67
Trz 11		09.6	−24 46	+3.69	+0.014	008.39	−02.18
6569		10.4	−31 50	+3.90	+0.015	000.49	−06.68
6584	Δ 376	14.6	−52 14	+4.79	+0.021	342.13	−16.38
6624		20.5	−30 23	+3.85	+0.030	002.80	−07.92
6626	M 26	21.5	−24 53	+3.69	+0.031	007.80	−05.58
6637	M 69	28.1	−32 23	+3.91	+0.041	001.72	−10.26
6638		27.9	−25 32	+3.71	+0.041	007.90	−07.16
6642		28.8	−23 30	+3.65	+0.042	009.82	−06.42
6652		32.5	−33 02	+3.93	+0.047	001.53	−11.38
6656	M 22	33.3	−23 58	+3.66	+0.048	009.87	−07.55
Pal 8		38.5	−19 52	+3.55	+0.056	014.11	−06.78
6681		40.0	−32 21	+3.91	+0.058	002.85	−12.52
6712		50.3	−08 47	+3.27	+0.073	025.34	−04.32
6715	M 54	51.9	−30 32	+3.84	+0.075	005.62	−14.09
6717	Pal 9	52.1	−22 47	+3.62	+0.075	012.86	−10.91
6723	Δ 573	56.2	−36 42	+4.04	+0.081	000.07	−17.30
6749		19 02.5	+01 42	+3.03	+0.090	036.06	−02.22
6752	Δ 295	06.4	−60 04	+5.30	+0.095	336.49	−25.62
6760		08.6	+00 57	+3.05	+0.099	036.10	−03.91
Trz 7		14.4	−34 45	+3.97	+0.107	003.38	−20.05
6779		14.6	+30 05	+2.34	+0.107	062.65	+08.34
Pal 10		16.0	+18 28	+2.65	+0.109	052.44	+02.68
1925−30	Arp 2	25.6	−30 27	+3.80	+0.122	008.56	−20.79
6809	M 55	36.9	−31 03	+3.81	+0.137	008.83	−23.28
Pal 11		42.6	−08 09	+3.25	+0.145	031.79	−15.60
6838	M 71	51.5	+18 39	+2.67	+0.156	056.74	−04.55
6864	M 75	20 03.2	−22 04	+3.54	+0.171	020.31	−25.76
6934		31.7	+07.14	+2.94	+0.205	052.10	−18.88
6981	M 72	50.7	−12 44	+3.30	+0.226	035.15	−32.68
7006		59.1	+16 00	+2.80	+0.235	063.77	−19.39
7078	M 15	21 27.6	+11 57	+2.90	+0.263	065.02	−27.32
7089	M 2	30.9	−01 03	+3.09	+0.266	053.37	−35.78
7099	M 30	37.5	−23 25	+3.41	+0.272	027.16	−46.83
Pal 12		47.3	−21 28	+3.37	+0.277	030.52	−47.64
Pal 13		23 04.2	+12 28	+3.00	+0.324	087.07	−42.72
7492		05.7	−15 54	+3.16	+0.325	053.32	−63.46

TABLE B. AUXILIARY QUANTITIES

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Cluster	cos *l*	sin *l*	cos *b*	sin *b*	sin *l* cos *b*	cos *l* cos *b*	|csc *b*|
104	+0.586	−0.810	0.708	−0.706	−0.574	+0.415	1.42
288	−0.863	+0.505	0.010	−1.000	+0.005	−0.009	1.00
362	+0.523	−0.825	0.691	−0.722	−0.589	+0.362	1.38
1261	+0.010	−1.000	0.614	−0.789	−0.614	+0.006	1.27
Pal 1	−0.634	+0.766	0.945	+0.327	+0.724	−0.608	3.06
Pal 2	−0.986	+0.165	0.988	−0.156	+0.163	−0.974	6.41
1851	−0.431	−0.902	0.819	−0.574	+0.739	−0.353	1.74
1904	−0.679	−0.734	0.872	−0.490	−0.640	−0.592	2.04
2298	−0.413	−0.911	0.961	−0.276	−0.876	−0.397	3.63
2419	−1.000	−0.006	0.904	+0.427	−0.006	−0.904	2.34
2808	+0.211	−0.978	0.981	−0.195	−0.959	+0.207	5.12
Pal 3	−0.498	−0.867	0.745	+0.667	−0.646	−0.371	1.50
3201	+0.126	−0.992	0.989	+0.150	−0.981	+0.124	6.66
Pal 4	−0.925	−0.380	0.312	+0.950	−0.118	−0.289	1.05
4147	−0.294	−0.954	0.222	+0.975	−0.212	−0.065	1.03
4372	+0.515	−0.857	0.985	−0.172	−0.844	+0.508	5.82
4590	+0.492	−0.869	0.809	+0.588	−0.703	+0.400	1.70
4833	+0.553	−0.833	0.990	−0.139	−0.825	+0.548	7.18
5024	+0.891	−0.454	0.178	+0.984	−0.081	+0.158	1.02
5053	+0.910	−0.413	0.192	+0.982	−0.079	+0.174	1.02
5139	+0.631	−0.768	0.966	+0.258	−0.750	+0.609	3.87
5272	+0.740	+0.672	0.196	+0.981	+0.132	+0.145	1.02
5286	+0.664	−0.748	0.983	+0.184	−0.735	+0.652	5.45
5466	+0.742	+0.670	0.282	+0.959	+0.190	+0.210	1.04
5634	+0.952	−0.305	0.653	+0.758	−0.199	+0.621	1.32
5694	+0.875	−0.484	0.863	+0.505	−0.418	+0.755	1.98
IC4499	+0.607	−0.795	0.937	−0.350	−0.744	+0.568	2.86
5824	+0.887	−0.461	0.927	+0.376	−0.427	+0.822	2.66
Pal 5	+1.000	+0.015	0.696	+0.718	+0.010	+0.696	1.39
5897	+0.956	−0.293	0.864	+0.504	−0.253	+0.826	1.98
5904	+0.998	+0.067	0.684	+0.729	+0.046	+0.683	1.37
5927	+0.835	−0.550	0.996	+0.085	−0.548	+0.832	11.8
5946	+0.844	−0.536	0.997	+0.073	−0.535	+0.842	13.7
5986	+0.921	−0.390	0.973	+0.230	−0.380	+0.896	4.35
1608+15	+0.877	+0.481	0.741	+0.671	+0.357	+0.650	1.49
6093	+0.992	−0.128	0.943	+0.333	−0.120	+0.935	3.00
6101	+0.740	−0.673	0.962	−0.273	−0.647	+0.712	3.67
6121	+0.988	−0.157	0.962	+0.275	−0.151	+0.950	3.64
6139	+0.953	−0.303	0.993	+0.121	−0.301	+0.946	8.28
6144	+0.990	−0.141	0.963	+0.270	−0.135	+0.953	9.70
6171	+0.998	+0.059	0.920	+0.391	+0.054	+0.919	2.56
6205	+0.515	+0.857	0.756	+0.654	+0.648	+0.390	1.53
6218	+0.963	+0.271	0.896	+0.443	+0.242	+0.863	2.26
6229	+0.282	+0.960	0.763	+0.647	+0.732	+0.242	1.55
6235	+1.000	−0.019	0.972	+0.234	−0.018	+0.972	4.28

TABLE B. AUXILIARY QUANTITIES (CONTINUED)

Cluster	cos *l*	sin*l*	cos*b*	sin*b*	sin*l*cos*b*	cos*l*cos*b*	|csc*b*|
6254	+0.965	+0.261	0.920	+0.392	+0.240	+0.888	2.55
6256	+0.978	−0.211	0.998	+0.059	−0.211	+0.996	17.1
Pal 15	+0.946	+0.324	0.912	+0.411	+0.295	+0.862	2.43
6266	+0.994	−0.112	0.992	+0.127	−0.111	+0.986	7.87
6273	+0.998	−0.055	0.987	+0.163	−0.054	+0.985	6.13
6284	+1.000	−0.028	0.985	+0.172	−0.028	+0.985	5.80
6287	+1.000	+0.003	0.982	+0.192	+0.002	+0.982	5.22
6293	+0.999	−0.041	0.991	+0.136	−0.041	+0.990	7.33
6304	+0.997	−0.072	0.996	+0.094	−0.072	+0.993	10.3
6316	+0.999	−0.049	0.995	+0.101	−0.049	+0.994	9.93
6325	+1.000	+0.017	0.990	+0.139	+0.017	+0.990	7.18
6333	+0.995	+0.096	0.982	+0.182	+0.095	+0.978	5.38
6341	+0.369	+0.930	0.821	+0.572	+0.763	+0.303	1.75
6342	+0.996	+0.085	0.986	+0.169	+0.084	+0.982	5.92
6352	+0.948	−0.319	0.992	−0.125	−0.317	+0.940	8.00
6355	+1.000	−0.007	0.996	+0.094	−0.007	+0.996	10.6
6356	+0.993	+0.117	0.984	+0.177	+0.115	+0.977	5.64
Trz 2	+0.998	−0.064	0.999	+0.040	−0.064	+0.997	24.9
6362	+0.824	−0.566	0.953	−0.302	−0.539	+0.786	3.31
6366	+0.949	+0.316	0.961	+0.276	+0.304	+0.912	3.62
Trz 4	+0.998	−0.069	1.000	+0.023	−0.069	+0.997	43.7
HP 1	+0.999	−0.045	0.999	+0.037	−0.045	+0.998	27.2
6380	+0.986	−0.168	0.998	−0.062	−0.168	+0.984	16.15
6388	+0.968	−0.250	0.993	−0.117	−0.248	+0.962	8.52
Trz 1	+0.999	−0.043	1.000	+0.017	−0.043	+0.999	57.9
Ton 2	+0.987	−0.160	0.998	−0.060	−0.160	+0.985	16.8
6397	+0.928	−0.372	0.978	−0.208	−0.364	+0.908	4.82
6401	+0.998	+0.060	0.998	+0.069	+0.060	+0.996	14.4
6402	+0.932	+0.363	0.967	+0.255	+0.351	+0.901	3.92
Pal 6	+0.999	+0.036	1.000	+0.031	+0.036	+0.999	32.2
6426	+0.882	+0.471	0.960	+0.280	+0.452	+0.847	3.58
Trz 5	+0.998	+0.067	1.000	+0.029	+0.067	+0.997	34.1
6440	+0.991	+0.134	0.998	+0.066	+0.134	+0.989	15.1
6441	+0.994	−0.113	0.996	−0.087	−0.112	+0.989	11.5
Trz 6	+1.000	−0.025	0.999	−0.038	−0.025	+0.999	26.5
6453	+0.997	−0.074	0.998	−0.069	−0.074	+0.995	14.4
6496	+0.978	−0.207	0.985	−0.174	−0.204	+0.964	5.75
Trz 9	+0.998	+0.063	0.999	−0.036	+0.063	+0.997	28.1
6517	+0.944	+0.329	0.993	+0.118	+0.327	+0.938	8.48
6522	+1.000	+0.018	0.998	−0.068	+0.018	+0.997	14.6
6528	+1.000	+0.020	0.997	−0.073	+0.020	+0.997	13.75
6535	+0.890	+0.457	0.984	+0.181	+0.449	+0.875	5.52
6539	+0.935	+0.355	0.993	+0.118	+0.353	+0.928	8.47
6541	+0.982	−0.186	0.981	−0.194	−0.182	+0.964	5.15
6544	+0.995	+0.102	0.999	−0.039	+0.102	+0.994	25.8

Cluster	cos*l*	sin*l*	cos*b*	sin*b*	sin*l*cos*b*	cos*l*cos*b*	csc*b*
6553	+0.996	+0.092	0.999	−0.053	+0.091	+0.994	18.7
6558	+1.000	+0.004	0.994	−0.104	+0.004	+0.995	9.57
IC1276	+0.928	+0.372	0.995	+0.099	+0.370	+0.924	10.1
Trz 11	+0.989	+0.146	0.999	−0.038	+0.146	+0.988	26.3
6569	+1.000	+0.009	0.993	−0.116	+0.008	+0.993	8.60
6584	+0.952	−0.307	0.959	−0.282	−0.294	+0.913	3.55
6624	+0.999	+0.049	0.990	−0.138	+0.048	+0.989	7.26
6626	+0.991	+0.136	0.995	−0.097	+0.135	+0.986	10.3
6637	+1.000	+0.030	0.984	−0.178	+0.030	+0.984	5.61
6638	+0.990	+0.137	0.992	−0.125	+0.136	+0.983	8.03
6642	+0.985	+0.171	0.994	−0.112	+0.170	+0.979	8.94
6652	+1.000	+0.027	0.980	−0.197	+0.026	+0.980	5.07
6656	+0.985	+0.171	0.991	−0.131	+0.170	+0.977	7.61
Pal 8	+0.970	+0.244	0.993	−0.118	+0.242	+0.963	8.47
6681	+0.999	+0.050	0.976	−0.217	+0.048	+0.975	4.61
6712	+0.904	+0.428	0.997	−0.075	+0.427	+0.901	13.3
6715	+0.995	+0.098	0.970	−0.243	+0.095	+0.965	4.11
6717	+0.975	+0.223	0.982	−0.189	+0.219	+0.957	5.28
6723	+1.000	+0.001	0.955	−0.297	+0.001	+0.955	3.36
6749	+0.808	+0.589	0.999	−0.039	+0.588	+0.808	25.8
6752	+0.917	−0.399	0.902	−0.432	−0.360	+0.827	2.31
6760	+0.808	+0.589	0.998	−0.068	+0.588	+0.806	14.7
Trz 7	+0.998	+0.059	0.939	−0.343	−0.055	+0.937	2.92
6779	+0.459	+0.888	0.989	+0.145	+0.879	+0.454	6.90
Pal 10	+0.610	+0.793	0.999	+0.047	+0.792	+0.609	21.4
1925−30	+0.989	+0.149	0.935	−0.355	+0.139	+0.924	2.84
6809	+0.988	+0.154	0.919	−0.395	+0.141	+0.908	2.53
Pal 11	+0.850	+0.529	0.963	−0.269	+0.507	+0.819	3.72
6838	+0.548	+0.836	0.997	−0.079	+0.834	+0.547	12.6
6864	+0.938	+0.347	0.901	−0.435	+0.313	+0.845	2.30
6934	+0.614	+0.789	0.946	−0.324	+0.745	+0.581	3.09
6981	+0.818	+0.576	0.842	−0.540	+0.485	+0.688	1.85
7006	+0.442	+0.897	0.943	−0.332	+0.846	+0.417	3.01
7078	+0.422	+0.906	0.888	−0.459	+0.805	+0.375	2.16
7089	+0.597	+0.802	0.811	−0.585	+0.651	+0.484	1.71
7099	+0.890	+0.457	0.684	−0.729	+0.312	+0.609	1.37
Pal 12	+0.862	+0.508	0.674	−0.739	+0.342	+0.580	1.35
Pal 13	+0.051	+0.999	0.735	−0.678	+0.734	+0.038	1.47
7492	+0.597	+0.802	0.447	−0.895	+0.358	+0.267	1.12

TABLE C. INTEGRAL MAGNITUDES, COLOR /112

Cluster	V	Wt	References	B–V	Wt	References
104	4.04	4.2	1, 2, 3	0.86	27	1, 2, 3, 18, 19
288	8.56	5.9	5, 6, 7, 8, 9	0.66	5	7, 8
362	6.42	1.4	3, 5	0.76	20	7, 8
1261	8.64	0.9	5, 10	0.70	15	10
Pal 1	–	–	–	–	–	–
Pal 2	–	–	–	1.5	0.1	20
1851	6.70	1.6	5, 9, 10, 17	0.77	17	10, 18
1904	7.84	3.7	4, 9, 11, 13	0.60	8	11, 18
2298	9.44	0.2	5, 9	0.74	4	18
2419	10.80	6.7	5, 6, 7, 8, 9, 11, 12, 16a	0.68	24	7, 11, 12, 13, 18
2808	6.13	0.9	3, 5	0.91	16	3, 18
Pal 3	14.5	0.2	14, 20	0.6:	1	14
3201	7.10	1.4	3, 17	0.97	17	3, 18
Pal 4	14.5	0.2	14, 20	0.6:	1	14
4147	10.28	7.8	5, 6, 8, 9, 11, 12, 15, 16 20	0.62	20	8, 11, 12, 15, 18
4372*)	8.0	0.1	5	0.87:	1	21
4590	8.25	4.2	3, 5, 6, 9, 12, 13	0.66	24	3, 12, 18
4833	7.36	1.4	3, 5, 17	0.96	17	3, 18
5024	7.71	10.2	3, 4, 5, 6, 8, 9, 11, 12 13, 16, 22, 23, 24	0.65	63	3, 4, 8, 11, 12, 18 22, 23, 25
5053	9.98	3.3	5, 8, 11, 12	0.63	10	11, 12
5139	3.65	2.5	1, 3	0.79	30	1, 3, 18
5272	6.41	11.0	3, 4, 5, 6, 8, 9, 11, 12, 13 15, 16, 22, 23, 24	0.69	68	3, 4, 8, 11, 12, 15 18, 22, 23, 25
5286	7.48	0.9	3, 5	0.90	15	3, 18
5466	9.35	2.6	5, 6, 8, 9, 12	0.75	8	8, 12
5634	9.58	3.3	5, 8, 10, 15, 16	0.68	27	3, 10, 12, 15, 18
5694	10.17	4.0	5, 8, 10, 12	0.72	24	3, 8, 12, 18
IC 4499	10.7	0.1	5	0.8:	0.1	20
5824	8.96	4.0	5, 8, 9, 10, 12	0.76	26	10, 18, 21
Pal 5	11.6	0.4	17, 20	–	–	–
5897	8.59	3.8	5, 8, 9, 12, 15	0.75	10	8, 12, 15
5904	6.03	14.5	3, 4, 5, 7, 8, 9, 11, 12, 13, 15, 16, 22, 23, 24	0.71	73	3, 4, 7, 8, 11, 12 15, 18, 22, 23, 25
5927	7.95	0.9	3, 5	1.31	17	3, 18
5946	9.11	0.7	3	1.19	14	3
5986	7.53	4.1	3, 5, 8, 9, 12	0.89	24	3, 8, 12, 18
1608+15	–	–	–	–	–	–
6093	7.31	4.7	3, 5, 8, 9, 12, 13, 22, 26	0.84	28	3, 8, 12, 18, 22
6101	8.9	0.1	5	1.0:	0.1	20
6121*	5.96	4.1	3, 5, 8, 9, 12, 13, 24, 26	1.04	20	3, 8, 12, 18
6139	8.99	1.2	5, 8	1.38	5	8, 18
6144	9.07	3.4	5, 8, 9, 11, 28	0.94	10	8, 12
6171	8.17	7.3	5, 8, 9, 11, 12, 13, 15, 16	1.13	19	11, 12, 15, 18
6205	5.86	10.9	4, 5, 7, 8, 9, 12, 13, 15, 16, 21, 23, 24	0.69	63	4, 7, 8, 12, 15, 18 22, 23, 25, 27
6218	6.88	10.1	3, 4, 5, 7, 8, 9, 12, 13, 15, 16, 24, 26	0.86	49	3, 4, 7, 8, 12, 15, 18
6229	9.39	8.3	5, 6, 8, 9, 11, 12, 13, 15, 16, 22	0.74	19	8, 11, 12, 15, 18 22
6235	10.23	0.7	5, 8, 28	0.88	2	8
6254	6.63	11.5	3, 4, 5, 7, 8, 9, 11, 13, 15 22, 23, 24, 26	0.92	67	3, 4, 7, 8, 12, 15 18, 22, 23, 25

* The quantity B–V was derived approximately indirectly according to [21].

TABLE C. UBVI EQUIVALENTS AND E (B-V) COLOR EXCESSES

Cluster	U–B	Wt	References	V–I	Wt	References	E (B–V)	Wt
104	0.34	16	3, 18, 21	1.42	8	2, 18	0.06	10
288	0.11	11	7	–	–	–	0.04	4
362	0.13	15	3, 18, 21	1.31	4	18	0.04	10
1261	0.12	9	10	–	–	–	0.02	8
Pal 1	–	–	–	–	–	–	0.19	3
Pal 2	–	–	–	–	–	–	0.73	2
1851	0.14	16	10, 18, 21	1.35	4	18	0.11	7
1904	0.04	18	11, 18, 21	1.19	4	18	0.01	4
2298	0.22	7	18, 21	1.44	4	18	0.12	7
2419	0.11	15	7, 13, 18	1.20	8	12, 18	0.05	8
2808	0.27	15	3, 18, 21	1.69	4	18	0.30	7
Pal 3	–	–	–	–	–	–	0.05	3
3201	0.38	14	3, 18, 21	1.64	4	18	0.21	6
Pal 4	–	–	–	–	–	–	0.03	3
4147	0.06	13	15, 18	1.06	8	12, 18	0.02	10
4372[a)]	0.28:	3	21	–	–	–	0.37	3
4590	0.03	17	3, 18, 21	1.18	8	12, 18	0.08	5
4833	0.31	15	3, 18, 21	1.68	4	18	0.33	8
5024	0.06	29	3, 18, 21, 23, 25	1.11	20	12, 18, 25	0.02	11
5053	–	–	–	1.16	4	18	0.05	6
5139	0.19	16	3, 18, 21	1.36	4	18	0.12	13
5272	0.10	41	3, 11, 15, 18, 23, 25	1.15	20	12, 18, 25	0.02	28
5286	0.29	16	3, 18, 21	1.51	4	18	0.20	7
5466	–	–	–	1.05	4	18	0.02	6
5634	0.13	19	10, 15, 18	1.25	6	12, 18	0.06	8
5694	0.07	13	10, 18	1.27	8	12, 18	0.12	7
IC 4499	–	–	–	–	–	–	0.19	2
5824	0.15	16	10, 18, 21	1.36	8	12, 18	0.15	7
Pal 5	–	–	–	–	–	–	0.15	3
5897	0.05:	4	15	1.28	4	12	0.13	12
5904	0.12	53*	3, 7, 10, 11, 15, 18, 23, 25	1.19	20	12, 18, 25	0.05	22
5927	0.83	14	3, 10	2.09	4	18	0.50	4
5946	0.43	3	3	–	–	–	0.55	1
5986	0.30	16	3, 18, 21	1.61	8	12, 18	0.25	7
1608+15	–	–	–	–	–	–	0.13	2
6093	0.20	17	3, 18, 21	1.44	8	12, 18	0.18	7
6101	–	–	–	–	–	–	0.26	1
6121[a)]	0.44	14	3, 18, 21	1.84	8	12, 18	0.35	9
6139	0.68	5	18, 21	2.45	4	18	0.65	4
6144	–	–	–	1.42	4	12	0.22	3
6171	0.52	22	11, 15, 18, 21	1.88	8	12, 18	0.35	17
6205	0.06	52	7, 15, 18, 21, 23, 25, 27	1.12	23	12, 18, 25, 27	0.02	22
6218	0.20	31	3, 7, 15, 18, 21	1.46	8	12, 18	0.18	17
6229	0.09	9	15, 18	1.25	8	12, 18	0.06	5
6235	–	–	–	–	–	–	0.24	1
6254	0.24	45	3, 7, 15, 18, 21, 23, 25	1.60	20	12, 18, 25	0.26	17

* The quantity E (B-V) is not the same for individual sections of the clusters.

TABLE C (CONTINUED)

Cluster	V	Wt	References	B–V	Wt	References
6256	–	–	–	–	–	–
Pal 15	–	–	–	–	–	–
6266	6.53	4.6	3, 5, 8, 9, 12, 13, 24, 26	1.14	25	3, 8, 12, 18
6273	6.83	3.2	3, 5, 7, 8, 9, 12, 13, 22, 24, 26, 28	1.00	31	3, 7, 8, 12, 18, 22
6284	9.03	3.5	5, 8, 9, 12, 28	0.97	11	8, 12, 18, 29
6287	9.44	3.4	5, 8, 9, 12, 28	1.26	8	8, 12
6293	8.39	8.3	3, 5, 7, 8, 9, 12, 13, 28	0.97	27	3, 7, 8, 12, 18
6304	8.38	8.3	3, 5, 7, 8, 9, 12, 28	1.32	32	3, 7, 8, 12, 18, 29, 30
6316	9.00	7.6	5, 7, 8, 9, 12, 28	1.30	12	7, 8, 12, 29
6325	10.73	3.4	5, 8, 9, 12, 28	1.69	6	12
6333	7.75	7.5	3, 5, 8, 9, 11, 12, 13, 16, 26, 28	0.96	31	3, 8, 11, 12, 18
6341	6.50	13.6	4, 5, 7, 8, 9, 11, 12, 13 15, 22, 23, 24	0.63	53	4, 7, 8, 11, 12, 15 18, 22, 23, 25, 27
6342	10.10	3.4	5, 8, 9, 12, 28	1.36	7	8, 12
6352	8.40	1.4	3, 5, 17	1.03	15	3
6355	9.76	2.7	5, 12	1.58	9	12
6356	8.28	9.1	3, 5, 8, 9, 11, 12, 13 16, 22, 23, 26, 28	1.14	51	3, 8, 11, 12, 18, : 22, 23, 25, 29
Trz 2	–	–	–	–	–	–
6362	8.23	0.9	3, 5	0.90	13	3
6366	10.09	1.2	5, 8, 15	1.60	4	8, 15
Trz 4	–	–	–	–	–	–
HP 1	–	–	–	2.0:	2	29
6380	–	–	–	–	–	–
6388	6.64	1.4	3, 5	1.16	18	3, 19
Trz 1	–	–	–	–	–	–
Ton 2	–	–	–	–	–	–
6397	5.90	0.9	3, 5	0.76	18	3, 19
6401	9.44	0.5	12	1.32	3	12
6402	7.48	13.1	3, 5, 7, 8, 9, 11, 12, 13 15, 16, 21, 23	1.26	44	3, 7, 8, 11, 12, 15 18, 21, 23
Pal 6	13.6	0.1	20	3.4	0.5	20
6426	11.48	2.1	5, 8, 9, 15	0.99	10	8, 12, 15
Trz 5	13.5	0.2	20, 31	4.0	1	20, 31
6440	9.39	3.4	5, 8, 9, 12, 28	1.97	14	8, 12, 18, 28, 29
6441	7.24	2.2	3, 5, 8, 9, 28	1.25	19	3, 8, 18
Trz 6	–	–	–	–	–	–
6453	9.77	1.6	5, 8, 12, 28	1.17	4	8, 12
6496	8.8	0.1	20	1.1:	1	20
Trz 9	–	–	–	–	–	
6517	10.29	8.1	5, 7, 8, 9, 12, 15	1.81	14	7, 8, 12, 15, 29
6522	8.75	8.3	3, 5, 7, 8, 9, 12, 28	1.20	29	3, 7, 8, 12, 18, 29
6528	9.67	2.8	5, 8, 9, 12, 28	1.43	12	8, 12, 18, 29
6535	10.62	6.7	5, 7, 8, 11, 15	0.96	13	7, 8, 11, 15, 29
6539	9.62	6.9	5, 8, 9, 11, 12, 15	1.91	16	8, 11, 12, 15
6541	6.91	0.9	3, 5	0.76	15	3
6544	8.30	1.6	12	1.46	9	12, 18
6553	8.13	7.7	5, 7, 8, 9, 12, 26, 28	1.63	14	7, 8, 12, 18, 27, 29
6558	–	–	–	–	–	–
IC 1276	–	–	–	–	–	–
Trz 11	–	–	–	–	–	–
6569	8.76	7.7	5, 7, 8, 9, 12, 28	1.29	9	7, 8, 12
6584	8.87	0.9	3, 5	0.79	15	3
6624	8.31	8.4	3, 5, 7, 8, 9, 12, 26, 28	1.10	28	3, 7, 8, 12, 18, 29
6626	6.99	2.7	3, 5, 7, 8, 9, 12, 13, 24 26, 28	1.09	30	3, 7, 8, 12, 18, 22
6637	7.79	4.4	3, 5, 8, 9, 12, 26, 28	1.02	24	3, 8, 12, 18
6638	9.03	7.7	5, 7, 8, 9, 12, 13, 26, 28	1.12	13	7, 8, 12, 18, 29

TABLE C (CONTINUED)

Cluster	U–B	Wt	References	V–I	Wt	References	E(B–V)	Wt
6256	–	–	–	–	–	–	–	–
Pal 15	–	–	–	–	–	–	–	–
6266*)	0.52	16	3, 18, 21	2.10	8	12, 18	0.42	6
6273	0.35	23	3, 7, 18, 21	1.73	8	12, 18	0.36	6
6284	0.36	4	18, 21	1.72	8	12, 18	0.29	5
6287	–	–	–	2.33	4	12	0.52	3
6293	0.27	23	3, 7, 18, 21	1.68	8	12, 18	0.35	6
6304	0.82	23	3, 7, 18, 21	2.26	8	12, 18	0.50	7
6316	0.57	12	7	2.42	4	12	0.60	5
6325	–	–	–	2.82	4	12	0.92	3
6333	0.30	25	3, 11, 18, 21	1.75	8	12, 18	0.39	6
6341	0.02	53	7, 11, 15, 18, 21, 23, 25, 27	1.10	23	12, 18, 25, 27	0.03	25
6342	–		–	1.95	4	12	0.50	3
6352	0.61	10	3, 21	–	–	–	0.34	6
6355	–	–	–	2.36	4	12	0.70	3
6356	0.58	45	3, 11, 18, 21, 23, 25	1.85	20	12, 18, 25	0.32	14
Trz 2	–	–	–	–	–	–	1.2:	1
6362	0.29	12	3, 21	–	–	–	0.15	7
6366	0.99	5	15	–	–	–	0.69	2
Trz 4	–	–	–	–	–	–	1.9:	1
HP 1	–	–	–	–	–	–	1.2	1.5
6380	–	–	–	–	–	–	0.7:	1
6388	0.62	14	3, 21	–	–	–	0.36	3
Trz 1	–	–	–	–	–	–	2.4:	0.5
Ton 2	–	–	–	–	–	–	0.65:	0.5
6397	0.15	14	3, 21	–	–	–	0.15	12
6401	–	–	–	2.52	2	12	0.74	1
6402	0.60	34	3, 7, 15, 18, 21, 23	2.10	8	12, 18	0.50	16
Pal 6	–	–	–	–	–	–	2.7:	0.5
6426	0.32	6	15	1.66	4	12	0.30	4
Trz 5	–	–	–	6.8	1	31	3.1	1
6440	0.9?	0	18	3.23	16	12, 18, 28	1.14	3
6441	0.79	16	3, 18, 21	2.16	4	18	0.46	4
Trz 6	–	–	–	–	–	–	1.1:	1
6453	–	–	–	2.53	2	12	0.66	2
6496	–	–	–	–	–	–	0.4:	1
Trz 9	–	–	–	–	–	–	–	
6517	0.99	10	7, 15	3.04	4	12	1.00	6
6522	0.64	19	3, 7, 12, 17	1.95	8	12, 18	0.47	11
6528	0.95	4	18	2.28	8	12, 18	0.66	7
6535	0.34	7	7, 15	–	–	–	0.33	4
6539	1.16	1	15	2.93	4	12	1.06	4
6541	0.14	14	3, 21	–	–	–	0.17	7
6544	0.68	4	18	2.50	8	12, 18	0.72	4
6553	1.06	7	7, 18, 21	2.89	16	12, 18, 27	0.82	6
6558	–	–	–	–	–	–	0.4:	1
IC 1276	–	–	–	–	–	–	0.7:	1
Trz 11	–	–	–	–	–	–	–	
6569	0.54	8	7, 21	2.12	4	12	0.52	4
6584	0.17	14	3, 21	–	–	–	0.06	3
6524	0.57	23	3, 7, 18, 21	1.84	8	12, 18	0.30	7
6626	0.45	25	3, 7, 18, 21	1.82	8	12, 18	0.38	9
6637	0.48	15	3, 18, 21	1.68	8	12, 18	0.18	9
6638	0.54	10	7, 18, 21	1.92	8	12, 18	0.37	6

* The quantity E (B-V) is not the same for individual sections of the clusters.

TABLE C (CONTINUED)

Cluster	V	Wt	References	B–V	Wt	References
6642	8.8	0.1	20	1.12	3	18
6652	8.93	4.2	3, 5, 8, 9, 12, 28	0.89	23	3, 8, 12, 18
6656	5.07	8.6	3, 5, 7, 8, 9, 12, 13, 22, 24, 26	1.00	29	3, 7, 8, 12, 18, 21
Pol 8	–	–	–	–	–	–
6681	8.18	4.2	3, 5, 8, 9, 12, 26	0.72	24	3, 8, 12, 18
6712	8.13	8.9	3, 5, 8, 9, 11, 12, 13, 15, 23, 26	1.14	41	3, 8, 11, 12, 15, 18, 23, 29
6715	7.61	4.2	3, 5, 8, 9, 12, 25	0.84	25	3, 8, 12, 18, 29
6717	–	–	–	–	–	–
6723	7.26	4.2	3, 5, 8, 9, 12, 26	0.74	27	3, 8, 12, 18, 19, 32
6749	11.07	0.7	15	1.63	2	15
6752	5.76	2.8	3, 5, 19	0.66	22	3, 32
6760	9.08	6.9	5, 8, 9, 11, 12, 15	1.68	17	8, 11, 12, 15, 27, 29
Trz 7	–	–	–	–	–	–
6779	8.21	6.7	5, 8, 9, 11, 12, 13, 22	0.87	32	8, 11, 12, 18, 22, 25, 29
Pal 10	–	–	–	–	–	–
1925–30	–	–	–	–	–	–
6809	6.33	7.3	5, 7, 9, 12, 24	0.69	25	3, 7, 8, 12, 18
Pal 11	–	–	–	–	–	–
6838	8.28	4.5	3, 6, 12, 15, 22	1.12	26	3, 12, 15, 18, 22
6864	8.52	4.6	3, 5, 8, 9, 12, 22	0.86	29	3, 8, 12, 18, 22, 29
6934	9.03	7.7	5, 8, 9, 11, 15, 16, 18, 22	0.77	22	8, 11, 12, 15, 18, 22, 29
6981	9.35	4.1	5, 8, 9, 12, 15	0.74	14	8, 12, 15, 18, 29
7006	10.67	12.1	5, 6, 7, 8, 9, 11, 12, 15, 22	0.74	28	7, 8, 11, 12, 15, 18, 22, 29
7078	6.48	10.8	3, 4, 5, 6, 7, 8, 9, 12, 13, 15, 22, 24	0.68	61	3, 4, 7, 8, 12, 15, 18, 22, 25, 27
7089	6.50	10.8	3, 4, 5, 6, 7, 8, 9, 12, 13, 15, 22, 24	0.68	60	3, 4, 7, 8, 12, 15, 18, 22, 25, 27
7099	7.56	9.1	3, 5, 6, 7, 8, 9, 12, 13, 22	0.60	31	3, 7, 8, 12, 18, 22
Pal 12	–	–	–	–	–	–
Pal 13	14.5	0.2	17, 20	0.7:	1	20
7492	11.48	5.9	5, 6, 7, 8, 9	0.40	5	7, 8

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TABLE C (CONTINUED)

Cluster	U–B	Wt	References	V–I	Wt	References	E(B–V)	Wt
6642	0.47	5	18, 21	1.86	4	18	0.38	3
6652	0.36	16	3, 18, 21	1.44	8	12, 18	0.13	6
6656	0.28	23	3, 7, 18, 21	1.83	8	12, 18	0.38	14
Pal 8	–	–	–	–	–	–	0.6:	1
6681	0.14	16	3, 18, 21	1.31	8	12, 18	0.04	6
6712	0.53	33	3, 11, 15, 18, 21, 23	2.00	8	12, 18	0.44	14
6715	0.24	17	3, 18, 21	1.44	8	12, 18	0.15	7
6717	–	–	–	–	–	–	0.4:	1
6723	0.26	16	3, 18, 21	1.36	8	12, 18	0.03	14
6749	–	–	–	–	–	–	0.92	2
6752	0.08	14	3, 21	–	–	–	0.04	7
6760	0.8:	0	15	2.80	14	12, 27	0.92	5
Trz 7	–	–	–	–	–	–	–	–
6779	0.21	30	11, 18, 21, 25	1.48	20	12, 18, 25	0.21	11
Pal 10	–	–	–	–	–	–	0.8:	1
1926–30	–	–	–	–	–	–	0.18	2
6809	0.12	32	3, 7, 18, 21	1.27	8	12, 18	0.08	11
Pal 11	–	–	–	–	–	–	0.24	2
6838	0.53	19	3, 15, 18, 21	1.81	8	12, 18	0.32	12
6864	0.28	17	3, 18, 21	1.52	8	12, 18	0.17	7
6934	0.20	18	11, 15, 18	1.24	8	12, 18	0.17	14
6981	0.11	7	15, 18	1.28	8	12, 18	0.06	13
7006	0.15	30	7, 15, 18, 21	1.22	8	12, 18	0.05	12
7078	0.06	53	3, 7, 15, 18, 21, 25, 27	1.18	23	12, 18, 25, 27	0.09	21
7089	0.08	55	3, 7, 15, 18, 21, 25, 27	1.17	23	12, 18, 25, 27	0.06	18
7099	0.04	29	3, 7, 18, 21	1.10	8	12, 18	0.06	14
Pal 12	–	–	–	–	–	–	0.07	2
Pal 13	–	–	–	–	–	–	0.02	2
7492	0.22	2	7	–	–	–	0.02	9

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NOTES TO TABLE C

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4372	The quantity B-V was calculated indirectly on the basis of [21].
6121	E(B-V) is not the same for individual sections of the cluster.
6266	E(B-V) is different for different parts of the clusters.
6341	Similarity with the x-ray source 3U 1736+43 is not excluded.
Trz 5	IRC-20385; K = 2.21; I-K = 5.23.
7078	In the center of the cluster a strong IR source was discovered at a wavelength of 10.2 (McGregor et al., 1973). Similarity with the x-ray source 3U 2131+11 is not excluded.

TABLE D. SPECTRA AND METAL CONTENTS

Cluster	Sp(CH/Hγ)	Wt	References	[m/H]	Wt	References
104	G2.6	8.6	1, 2, 3, 4, 5	−0.52	2.0	1, 4, 5, 11, 13, 14, 15
288	(F6)	2.0	5	−1.37	0.6	1, 5, 13
362	F8.3	8.6	1, 2, 3, 4, 5	−0.98	1.7	1, 4, 5, 11, 13, 14, 15
1261	F7.7	8.0	1, 2, 5	−1.25	0.8	5, 11, 13
1851	F7.0	6.5	1, 4, 5, 6	−1.00	1.0	1, 4, 5, 11, 13
1904	F5.7	8.5	1, 4, 5, 6, 7	−1.46	1.1	1, 4, 5, 7
2298	F6.7	3.5	4, 5, 6	−1.46	1.3	4, 5, 11, 13
2419	F5.5	4.0	5, 6, 7	−1.48	0.6	5, 7
2808	F7.2	8.5	1, 2, 4, 5	−1.38	1.2	1, 4, 5, 11
3201	(F9)	2.5	4, 5	−1.36	1.6	1, 4, 5, 11, 13, 14
Pal 4	(F6)	0.5	5	−1.15	0.6	11, 13
4147	F3.8	4.0	5, 6, 7	−1.56	1.8	1, 5, 7, 11, 13, 14
4372	(F3)	1.0	4, 5	−1.59	1.0	1, 4, 5, 11, 13
4590	F2.7	4.5	4, 5, 6, 7	−1.95	1.3	4, 5, 7, 11, 14
4933	(F4)	2.5	3, 4, 5	−1.67	1.4	1, 4, 5, 11, 13
5024	F4.2	9.0	4, 5, 6, 7, 8, 9, 10	−1.75	4.1	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
5053	(F3)	2.0	5	−1.87	1.1	1, 11, 13, 14
5139	F6.6	7.6	1, 3, 4, 5, 8	−1.55	2.4	1, 4, 5, 8, 11, 13, 14, 15
5272	F6.1	9.0	3, 4, 5, 6, 7, 8, 9, 10	−1.44	4.3	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
5286	F7.3	7.5	1, 2, 4, 5	−1.25	0.8	1, 4, 5
5466	(F5)	1.7	5	−1.87	1.2	1, 11, 13, 14
5634	F5.1	2.5	5, 6	−1.50	0.4	5
5694	F3.0	3.5	5, 6, 7	−1.92	0.6	5, 7
5824	F4.3	5.0	4, 5, 6, 7	−1.79	1.0	4, 5, 7
5897	(F3)	2.0	5	−1.85	1.4	1, 5, 11, 13, 15
5904	F6.1	9.0	4, 5, 6, 7, 8, 9, 10	−1.34	4.5	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15
5927	G2.8	5.0	1, 4, 5	+0.9	0.8	4, 5
5946	(F5)	0.8	5	−1.6:	0.2	5
5986	F6.3	7.5	2, 4, 5, 6, 7	−1.39	0.9	4, 5, 7
6093	F5.9	6.0	4, 5, 6, 7, 9	−1.45	2.2	1, 4, 5, 7, 9, 12
6121	F6.9	3.5	4, 5, 7	−1.11	2.4	1, 4, 5, 7, 11, 13, 14, 15
6139	F8.7	5.0	1, 4, 5	−0.70	0.7	4, 5
6144	(F7)	0.5	5	—	—	—
6171	G0.0	4.5	4, 5, 6, 7	−0.80	1.8	4, 5, 7, 11, 13, 14
6205	F5.4	9.0	3, 4, 5, 6, 7, 8, 9, 10	−1.53	4.1	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
6218	F5.7	5.0	4, 5, 6, 7, 9	−1.52	1.8	1, 4, 5, 7, 9, 11, 13
6229	F7.3	7.0	5, 6, 7, 8	−1.36	1.9	5, 7, 8, 12, 14
6235	(F5)	0.2	5	—	—	—
6254	F6.4	6.1	3, 4, 5, 6, 7, 9, 10	−1.47	3.7	1, 4, 5, 7, 8, 9, 10, 11, 12, 13
6266	F8.1	14.5	1, 2, 4, 5, 6, 7, 8	−0.99	1.3	1, 4, 5, 7, 14
6273	F5.3	8.6	3, 4, 5, 6, 7, 8	−1.23	1.8	4, 5, 7, 8, 12
6284	F7.8	7.0	4, 5, 6, 7, 8	−1.30	0.8	4, 5, 7
6287	(G3)	0.4	5	—	—	—
6293	F4.1	7.0	4, 5, 6, 7, 8	−1.74	0.9	4, 5, 7
6304	G4.6	7.0	4, 5, 6, 7, 8	+0.08	0.9	4, 5, 7
6316	(F9)	1.5	5	−0.89	0.5	4, 5
6325	(G1)	0.3	5	—	—	—
6333	F2.8	7.0	4, 5, 6, 7, 8	−1.71	1.0	4, 5, 7, 14
6341	F2.8	9.0	4, 5, 6, 7, 8, 9, 10	−1.99	4.4	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
6342	(G2)	0.3	5	—	—	—
6352	(G2)	2.3	4, 5	−0.11	1.0	4, 5, 11, 13
6355	(G4)	0.3	5	—	—	—
6356	G3.4	11.1	3, 4, 5, 6, 7, 8, 9, 10	−0.21	3.5	4, 5, 7, 8, 9, 10, 11, 12, 13

TABLE D (CONTINUED)

Cluster	Sp(CH/Hγ)	Wt	References	[m/H]	Wt	References
6352	(F9)	1.9	4, 5	−1.08	1.5	1, 4, 5, 11, 13, 14
6366	(G5)	0.5	5	±0.1:	0.2	5
HP 1	(G5):	0.1	5	−	−	−
6388	G2.5	7.6	1, 2, 3, 4, 5	−0.10	0.8	1, 4, 5
6397	F4.8	8.1	1, 2, 3, 4, 5	−1.48	1.5	1, 4, 5, 11, 13
6401	(F4)	0.2	5	−	−	−
6402	F8.1	5.0	4, 5, 6, 7, 9	−1.14	3.0	4, 5, 7, 8, 11, 13, 14
6426	(F6)	1.0	5	−1.57	0.4	5
Trz 5	(G5)	0.1	5	−	−	−
6440	G4.6	7.7	5, 6, 7, 8	−0.24	0.9	5, 7, 8
6441	G2.6	9.1	2, 3, 4, 5, 6, 8	−0.02	0.7	4, 5
6453	(F2)	0.3	5	−	−	−
6517	(G2)	1.1	5	−0.5:	0.3	5
6522	F8.7	4.6	3, 4, 5, 6, 7	−0.86	1.8	4, 5, 7, 8, 11, 13
6528	G3.4	3.2	3, 4, 5, 7	+0.06	1.3	1, 4, 5, 7, 11
6535	(F6)	0.8	5	−0.7::	0.1	5
6539	(G3)	0.7	5	+0.1::	0.1	5
6541	F5.4	8.1	1, 2, 4, 5	−1.61	1.3	1, 4, 5, 11, 13
6544	F8.8	2.1	5, 6	−0.94	0.4	5
6553	G3.2	3.6	3, 4, 5, 7	−0.22	1.6	4, 5, 7, 8, 11, 13
6569	(G0)	1.6	5	−0.81	0.5	4, 5
6584	G0.2	7.5	1, 2, 4, 5	−1.00	0.6	4, 5
6624	G2.5	7.0	4, 5, 6, 7, 8	−0.24	0.9	4, 5, 7
6626	F8.5	7.0	4, 5, 6, 8, 9	−0.90	1.7	4, 5, 9, 12
6637	G4.8	12.6	2, 3, 4, 5, 6, 7, 8	−0.18	1.8	4, 5, 7, 8, 11, 13
6638	G0.7	6.0	4, 5, 6, 8	−0.65	0.6	4, 5
6642	F9.2	3.2	3, 4, 5, 7	−0.82	1.1	4, 5, 7
6652	G1.3	6.0	4, 5, 6, 8	−0.68	0.7	4, 5
6656	F4.8	5.1	3, 4, 5, 6, 8, 9	−1.68	3.3	1, 4, 5, 7, 8, 9, 11, 12, 13, 14, 15
6681	F7.7	6.0	2, 4, 5, 6	−1.34	0.7	4, 5
6712	G0.3	7.6	3, 4, 5, 6, 7, 8	−0.83	1.8	4, 5, 7, 8, 11, 13
6715	F7.9	11.6	1, 2, 3, 4, 5, 6, 7	−1.17	1.4	4, 5, 7, 8, 14
6723	F9.8	3.6	3, 4, 5, 6	−0.79	1.1	4, 5, 11, 13, 14
6749	(F8)	0.1	5	−	−	−
6752	F5.6	8.3	1, 2, 3, 4, 5	−1.52	1.6	1, 4, 5, 11, 13, 15
6760	(G0)	1.2	5	−0.76	0.5	1, 5
6779	F4.6	5.5	4, 5, 6, 7, 10	−1.77	3.2	1, 4, 5, 7, 10, 11, 12, 13
6809	F4.7	3.6	3, 4, 5, 7	−1.55	1.4	1, 4, 5, 7, 9
6838	G2.1	7.1	3, 4, 5, 6, 8, 9	−0.36	2.7	4, 5, 8, 9, 11, 12, 13
6864	F8.2	7.5	1, 4, 5, 6	−1.18	1.3	4, 5, 12
6934	F5.7	3.0	5, 6	−1.49	1.8	5, 11, 12, 13
6981	F7.5	3.1	3, 5, 6	−1.38	1.4	5, 8, 11, 13, 14
7006	F4.9	4.5	4, 5, 6, 7	−1.50	2.6	4, 5, 7, 8, 11, 12, 13, 14
7078	F3.2	12.1	1, 3, 4, 5, 6, 7, 8, 9, 10	−2.02	4.5	1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14
7089	F4.0	10.1	1, 3, 4, 5, 6, 7, 9, 10	−1.72	4.2	1, 4, 5, 7, 8, 9, 10, 11, 13, 14, 15
7099	F2.8	11.5	1, 2, 4, 5, 6, 7	−1.78	2.3	1, 4, 5, 7, 11, 12, 13
Pal 13	(F6)	0.1	5	−1.25::	0.1	11, 14
7492	(F5)	0.2	5	−1.2:	0.6	5, 11, 13

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TABLE E. DIAMETERS AND APPARENT DISTANCE MODULI

Cluster	lg d	Wt	References	Mod^{V}_{app}	Wt	Methods of determination
104	1.49	7	1, 2, 3, 4	13.12	3,8	2, 3, 4, 5, 6, 7, 8
288	1.14	25	1, 2, 3, 4, 5, 6	14.44	0.3	4, 6, 7, 8
362	1.11	7	1, 2, 3, 4	14.57	3.1	1, 2, 3, 4, 7, 8
1261	0.84	6	1, 2, 4	15.55	2.8	1, 2, 7, 8
Pal 1	0.25	16	1, 4, 7	18.9	0.04	3, 7, 8
Pal 2	0.28	14	4, 7	19.3	0.04	2, 7, 8
1851	1.04	11	1, 2, 3, 4	15.17	2.7	1, 2, 4, 7, 8
1904	0.94	31	1, 2, 3, 4, 5	15.60	0.4	1, 3, 4, 7, 8
2298	0.83	16	2, 3, 4, 5	15.39	1.4	1, 2, 4, 7, 8
2419	0.61	28	1, 2, 3, 4, 5, 6	19.07	0.7	1, 3, 6, 7, 8
2808	1.14	7	1, 2, 3, 4	15.66	2.5	1, 2, 3, 4, 7, 8
Pal 3	0.44	15	1, 4, 7	19.5	0.2	1, 2, 7, 8
3201	1.26	17	1, 2, 3, 4	13.77	3.1	1, 2, 7, 8
Pal 4	0.33	15	1, 4, 7	19.24	1.5	1, 2, 6, 7, 8
4147	0.60	33	1, 2, 3, 4, 5, 6, 8	16.37	3.2	1, 2, 3, 4, 7, 8
4372	1.27	6	2, 3, 4	14.31	2.6	1, 2, 7, 8
4590	1.08	33	1, 2, 4, 5, 6, 8	15.24	0.6	1, 3, 4, 7, 8
4833	1.13	7	2, 3, 4	14.54	3.0	1, 2, 4, 6, 7, 8
5024	1.10	34	1, 2, 3, 4, 5, 6, 8	16.17	3.4	1, 2, 3, 4, 5, 6, 7, 8
5053	1.02	24	1, 2, 4, 5	15.75	1.6	1, 2, 3, 7, 8
5139	1.56	8	1, 2, 3, 4	13.81	4.2	1, 2, 4, 6, 7, 8
5272	1.21	32	1, 2, 3, 4, 5, 6, 8	14.79	4.4	1, 2, 3, 4, 6, 7, 8, 9
5286	0.96	6	2, 3, 4	15.4	0.2	4, 7, 8
5466	1.04	30	1, 2, 4, 5, 6	15.83	3.1	1, 2, 3, 7, 8
5634	0.69	26	1, 2, 3, 4, 5	16.59	0.3	1, 3, 7, 8
5694	0.56	28	4, 5, 8	17.9	0.2	3, 7, 8
IC 4499	0.88	6	2, 4	15.3	0.02	7, 8
5824	0.79	24	1, 2, 3, 4, 5, 8	17.12	0.4	1, 7, 8
Pal 5	0.84	15	1, 4, 7, 9	16.3	0.1	1, 3, 7, 8
5897	1.10	35	1, 2, 3, 4, 5, 8	15.56	3.0	1, 2, 3, 4, 6, 7, 8
5904	1.24	34	1, 2, 3, 4, 5, 8	14.29	4.0	1, 2, 3, 4, 6, 7, 8
5927	1.08	6	2, 3, 4	15.52	0.4	6, 7, 8
5946	0.85	5	2, 4	16.2	0.1	4, 7, 8
5986	0.99	17	1, 2, 3, 4, 5, 8	15.4	0.2	1, 4, 6, 7, 8
1609+15	0.32	12	1, 4	–	–	–
6093	0.95	35	1, 2, 3, 4, 5, 8	15.47	0.5	1, 4, 7, 8, 9
6101	1.03	6	2, 3, 4	14.6	0.03	4, 7, 8
6121	1.42	35	1, 2, 3, 4, 5, 8	12.53	3.0	1, 2, 3, 6, 7, 8
6139	0.74	9	2, 4	16.9	0.06	7, 8
6144	0.97	34	2, 3, 4, 5, 8	15.0	0.1	3, 4, 7, 8
6171	1.00	33	2, 3, 4, 5, 8	14.65	3.3	1, 2, 3, 4, 6, 7, 8
6205	1.22	31	1, 2, 3, 4, 5, 8	14.06	3.2	1, 2, 3, 6, 7, 8, 9
6218	1.16	34	1, 2, 3, 4, 5, 8	14.17	2.9	1, 2, 3, 4, 7, 8, 9
6229	0.65	32	1, 2, 3, 4, 5, 6, 8	16.85	0.5	1, 3, 6, 7, 8, 9
6235	0.70	22	2, 3, 4	16.3	0.1	3, 7, 8
6254	1.18	33	1, 2, 3, 4, 5, 8	13.97	3.0	1, 2, 3, 4, 7, 8, 9
6266	1.15	35	2, 3, 4, 5, 8	15.44	0.65	1, 3, 4, 7, 8
6273	1.13	26	2, 3, 4, 5, 8	15.10	0.23	3, 4, 7, 8
6284	0.75	26	2, 3, 4, 5, 8	16.22	0.23	3, 4, 7, 8
6287	0.71	26	2, 3, 4, 5, 8	16.0	0.1	3, 7, 8
6293	0.90	26	2, 3, 4, 5, 8	15.91	0.25	3, 4, 7, 8
6304	0.83	25	2, 3, 4, 5, 8	15.5	0.15	4, 7, 8
6316	0.69	26	2, 3, 4, 5, 8	16.8	0.1	7, 8
6325	0.63	26	2, 3, 4, 5, 8	17.6	0.1	7, 8
6333	0.97	34	1, 2, 3, 4, 5, 8	15.87	0.45	1, 3, 4, 7, 8
6341	1.05	30	1, 2, 4, 5, 8	14.43	3.0	1, 2, 3, 7, 8
6342	0.47	26	2, 3, 4, 5, 8	18.3	0.1	7, 8
6352	0.85	6	2, 3, 4	13.90	2.8	1, 2, 4, 6, 7, 8

TABLE E (CONTINUED)

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Cluster	lg d	Wt	References	Mod^{V}_{app}	Wt	Methods of determination
6355	0.70	18	4, 8	16.4	0.1	7, 8
6356	0.86	34	2, 3, 4, 5, 8	16.37	3.0	1, 2, 3, 4, 5
Trz 2	0.17	7	4	–	–	–
6362	1.03	9	1, 2, 3, 4	14.14	2.9	1, 2, 4, 7, 8
6366	0.92	22	1, 2, 4, 5	14.7	0.1	3, 7, 8
Trz 4	0.00	4	4	–	–	–
HP 1	0.45	9	4	–	–	–
6380	0.59	5	4	–	–	–
6388	0.94	8	2, 3, 4	14.9	0.1	7, 8
Trz 1	0.44	4	4	–	–	–
Ton 2	0.53	4	4	–	–	–
6397	1.41	7	1, 2, 3, 4	11.90	2.7	1, 2, 3, 4, 7, 8
6401	0.75	20	2, 4	16.3	0.1	7, 8
6402	1.07	34	1, 2, 3, 4, 5, 8	16.43	4.55	1, 2, 3, 6, 7, 8, 9
Pal 6	0.86	14	4, 7	19.3	0.03	3, 7, 8
6426	0.50	23	2, 4, 5	17.08	0.3	1, 7, 8
Trz 5	0.32	2	4	23.0	0.01	7, 8
6440	0.73	23	2, 4, 5, 8	17.1	0.1	7, 8
6441	0.89	16	2, 3, 4, 5	16.0	0.2	4, 7, 8
Trz 6	0.07	4	4	–	–	–
6453	0.54	12	2, 3, 4	17.9	0.1	7, 8
6496	0.84	6	2, 3, 4	14.4	0.04	4, 7, 8
6517	0.63	21	2, 4, 5, 8	18.2	0.1	7, 8
6522	0.75	24	2, 4, 5, 8	15.22	2.8	1, 2, 4, 7, 8
6528	0.57	24	2, 4, 5, 8	15.91	1.7	1, 2, 4, 7, 8
6535	0.56	19	2, 4	15.7	0.2	3, 7, 8
6539	0.84	24	1, 2, 4, 5, 8	16.0	0.1	7, 8
6541	1.12	11	1, 2, 3, 4	14.32	2.8	1, 2, 3, 4, 7, 8
6544	0.95	18	4, 8	15.1	0.15	4, 7, 8
6553	0.91	25	2, 3, 4, 5, 8	15.1	0.1	7, 8
6558	0.57	17	4	–	–	–
IC 1276	0.85	16	1, 4, 7, 9	18.0	0.2	1, 3, 6, 7, 8
6569	0.76	21	2, 4, 5, 8	15.7	0.1	7, 8
6584	0.90	6	2, 3, 4	15.7	0.15	4, 7, 8
6624	0.77	21	2, 4, 5, 8	16.2	0.1	7, 8
6626	1.05	27	2, 3, 4, 5, 8	14.96	0.65	1, 3, 4, 6, 7, 8, 9
6637	0.85	25	2, 3, 4, 5, 8	14.53	2.8	1, 2, 4, 5, 6, 7, 8
6638	0.70	34	2, 3, 4, 5, 8	16.7	0.15	3, 7, 8
6642	0.65	20	2, 4	16.1	0.05	4, 7, 8
6652	0.55	17	2, 3, 4, 5, 8	16.6	0.15	4, 7, 8
6656	1.38	35	1, 2, 3, 4, 5, 8	13.33	3.2	1, 2, 3, 4, 6, 7, 8, 9
Pal 8	0.67	16	4, 7	–	–	–
6681	0.89	25	2, 3, 4, 5, 8	15.7	0.15	4, 7, 8
6712	0.86	22	2, 4, 5, 8	15.09	3.4	1, 2, 3, 4, 5, 6, 7, 8
6715	0.96	26	1, 2, 3, 4, 5, 8	16.20	0.5	1, 6, 7, 8, 9
6717	0.59	14	4, 7	–	–	–
6723	1.04	26	1, 2, 3, 4, 5, 8	14.63	3.4	1, 2, 3, 4, 6, 7, 8
6749	0.80	12	4	16.3	0.08	7, 8
6752	1.31	7	1, 2, 3, 4	13.11	2.8	1, 2, 3, 7, 8
6760	0.82	21	2, 4, 5, 8	15.9	0.2	3, 7, 8
6779	0.85	30	2, 3, 4, 5, 8	15.37	2.9	1, 2, 3, 4, 6, 7, 8, 9
Pal 10	0.54	14	4, 7	–	–	–
1927–30	0.57	12	4	–	–	–
6809	1.28	33	1, 2, 3, 4, 5, 8	13.6	0.2	3, 7, 8
Pal 11	0.50	15	4, 7, 9	–	–	–
6838	0.86	23	4, 5, 6, 8	13.39	2.9	1, 2, 3, 4, 6, 7, 8
6864	0.78	33	2, 3, 4, 5, 8	17.0	0.15	3, 7, 8
6934	0.77	32	1, 2, 4, 5, 8	16.03	3.2	1, 2, 3, 4, 7, 8
6981	0.77	34	1, 2, 3, 4, 5, 8	16.12	3.0	1, 2, 3, 7, 8
7006	0.45	32	1, 2, 4, 5, 6, 8	17.91	3.3	1, 2, 3, 6, 7, 8
7078	1.09	35	1, 2, 3, 4, 5, 6, 8	15.22	3.7	1, 2, 3, 4, 7, 8, 9
7089	1.11	34	1, 2, 3, 4, 5, 6, 8	15.43	3.4	1, 2, 3, 4, 7, 8, 9
7099	1.04	35	1, 2, 3, 4, 5, 6, 8	14.62	2.9	1, 2, 3, 4, 7, 8
Pal 12	0.45	15	4, 7, 9	–	–	–
Pal 13	0.25	15	4, 7, 9	16.70	1.1	1, 7
7492	0.79	25	1, 2, 4, 5, 9	16.18	2.9	1, 2, 3, 7, 8, 9

References for diameter measurements

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Methods of determining distance moduli

1. RR Lyrae and horizontal branch stars.
2. The bright stars (Table 10 of this book).
3. The bright stars according to S. van den Bergh, 1965.
4. Moduli according to visual determinations of S. van den Bergh, 1967.
5. Mira-Cetus type stars.
6. Red variable stars.
7. The diameters of globular clusters.
8. Richness indices IR,
9. Cepheids.

NOTES TO TABLE E

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Table E does not include the Mod^{V}_{app} values for the following clusters, since their accuracy is very low.

1608+15	18.6::	Trz 1	22.2::	6717	16.3::
Trz 2	20.6::	Ton 2	18.2::	Pal 10	18.5:
Trz 4	23.4::	Trz 6	20.2::	1925-30	15.5::
HP 1	18.5::	6558	16.3:	Pal 11	16.7:
6380	17.0::	Pal 8	18.0:	Pal 12	16.8:

TABLE F. GENERAL DATA

Cluster	V	B–V	U–B	V–I	Sp	[m/H]	Cluster
104	4.04	0.86	0.34	1.42	G2.6	–0.52	104
288	8.56	0.66	0.11	–	(F6)	–1.37	288
362	6.42	0.76	0.13	1.31	F8.3	–0.98	362
1261	8.64	0.70	0.12	–	F7.7	–1.25	1261
Pal 1	–	–	–	–	–	–	Pal 1
Pal 2	–	1.5:	–	–	–	–	Pal 2
1851	6.70	0.77	0.14	1.35	F7.0	–1.00	1851
1904	7.84	0.60	0.04	1.19	F5.7	–1.46	1904
2298	9.44	0.74	0.22	1.44	F6.7	–1.46	2298
2419	10.80	0.68	0.11	1.20	F5.5	–1.48	2419
2808	6.13	0.91	0.27	1.69	F7.2	–1.38	2808
Pal 3	14.5	0.6:	–	–	–	–	Pal 3
3201	7.10	0.97	0.38	1.64	(F9)	–1.36	3201
Pal 4	14.5	0.6:	–	–	(F6)	–1.15	Pal 4
4147	10.28	0.62	0.06	1.06	F3.8	–1.56	4147
4372	8.0	0.87:	0.28:	–	(F3)	–1.59	4372
4590	8.25	0.66	0.03	1.18	F2.7	–1.95	4590
4833	7.36	0.96	0.31	1.66	(F4)	–1.67	4833
5024	7.71	0.65	0.06	1.11	F4.2	–1.75	5024
5053	9.98	0.63	–	1.16	(F3)	–1.87	5053
5139	3.65	0.79	0.19	1.36	F6.6	–1.55	5139
5272	6.41	0.69	0.10	1.15	F6.1	–1.44	5272
5286	7.48	0.90	0.29	1.51	F7.3	–1.25	5286
5466	9.35	0.75	–	1.05	(F5)	–1.87	5466
5634	9.58	0.68	0.13	1.25	F5.1	–1.50	5634
5694	10.17	0.72	0.07	1.27	F3.0	–1.92	5694
IC 4499	10.7	0.8:	–	–	–	–	IC 4499
5824	8.96	0.76	0.15	1.38	F4.3	–1.79	5824
Pal 5	11.6:	–	–	–	–	–	Pal 5
5897	8.59	0.75	0.05:	1.28	(F3)	–1.85	5897
5904	6.03	0.71	0.12	1.19	F6.1	–1.34	5904
5927	7.95	1.31	0.83	2.09	G2.8	+0.09	5927
5946	9.11	1.19	0.43	–	(F5)	–1.6:	5946
5986	7.53	0.89	0.30	1.61	F6.3	–1.39	5986
1608+15	–	–	–	–	–	–	1608+15
6093	7.31	0.84	0.20	1.44	F5.9	–1.45	6093
6101	8.9:	1.0:	–	–	–	–	6101
6121	5.96	1.04	0.44	1.84	F6.9	–1.11	6121
6139	8.99	1.38	0.68	2.45	F8.7	–0.70	6139
6144	9.07	0.94	–	1.42	(F7)	–	6144

TABLE F (CONTINUED)

Cluster	E (B−V)	Mod_0^V	t kps	lg d	D ps	M_0^V	Cluster
104	0.06	12.96	3.9	1.49	35	−9.08	104
288	0.04	14.32	7.3	1.14	29	−5.88	288
362	0.04	14.45	7.8	1.11	29	−8.15	362
1261	0.02	15.49	12.5	0.84	25	−6.91	1261
Pal 1	0.19	18.3	46	0.25	24	−	Pal 1
Pal 2	0.73	17.1	26	0.28	14	−	Pal 2
1851	0.11	14.84	9.3	1.04	30	−8.47	1851
1904	0.01	15.57	13.0	0.94	33	−7.76	1904
2298	0.12	15.03	10.1	0.83	20	−5.95	2298
2419	0.05	18.92	61	0.61	72	−8.27	2419
2808	0.30	14.76	9.0	1.14	36	−9.53	2808
Pal 3	0.05	19.4	76	0.44	61	−5.0	Pal 3
3201	0.21	13.14	4.2	1.26	22	−6.67	3201
Pal 4	0.03	19.15	68	0.33	42	−4.7	Pal 4
4147	0.02	16.31	18.3	0.60	21	−6.09	4147
4372	0.37	13.2	4.4	1.27	24	−6.8	4372
4590	0.08	15.00	10.0	1.08	35	−6.99	4590
4833	0.33	13.55	5.1	1.13	20	−7.18	4833
5024	0.02	16.11	16.7	1.10	61	−8.46	5024
5053	0.05	15.60	13.2	1.02	40	−5.77	5053
5139	0.12	13.45	4.9	1.56	52	−10.16	5139
5272	0.02	14.73	8.8	1.21	42	−8.38	5272
5286	0.20	14.8	9.1	0.96	24	−7.9	5286
5466	0.02	15.77	14.3	1.04	46	−6.48	5466
5634	0.06	16.41	19.1	0.69	27	−7.0	5634
5694	0.12	17.5	32	0.56	34	−7.7	5694
IC 4499	0.19	14.7:	9.7:	0.88	20	−4.6:	IC 4499
5824	0.15	16.67	21.6	0.79	39	−8.16	5824
Pal 5	0.15	15.9	15.1	0.84	30	−4.7:	Pal 5
5897	0.13	15.17	10.8	1.10	40	−6.97	5897
5904	0.05	14.14	6.7	1.24	34	−8.26	5904
5927	0.50	14.02	6.4	1.08	22	−7.57	5927
5946	0.55	14.6	8	0.85	17	−7.1	5946
5986	0.25	14.7	8.7	0.99	25	−7.9	5986
1608+15	0.13	−	−	0.32	−	−	1608+15
6093	0.18	14.93	9.7	0.95	25	−8.16	6093
6101	0.26	13.8	6	1.03	19	−5.7:	6101
6121	0.36	11.45	2.0	1.42	15	−6.57	6121
6139	0.65	15.0	10	0.74	16	−7.9	6139
6144	0.22	14.4	8	0.97	22	−6.0	6144

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TABLE F (CONTINUED)

uster	V	B-V	U-B	V-I	Sp	[m/H]	Cluster
6171	8.17	1.13	0.52	1.88	G0.0	-0.80	6171
6205	5.86	0.69	0.06	1.12	F5.4	-1.53	6205
6218	6.88	0.86	0.20	1.46	F5.7	-1.52	6218
6229	9.39	0.74	0.09	1.25	F7.3	-1.36	6229
6235	10.23	0.88	-	-	(F5)	-	6235
6254	6.63	0.92	0.24	1.60	F6.4	-1.47	6254
6256	-	-	-	-	-	-	6256
l 15	-	-	-	-	-	-	Pol 15
6266	6.53	1.14	0.52	2.10	F8.1	-0.99	6266
6273	6.83	1.00	0.35	1.73	F5.3	-1.23	6273
6284	9.03	0.97	0.36	1.72	F7.8	-1.30	6284
6287	9.44	1.26	-	2.33	(G3)	-	6287
6293	8.39	0.97	0.27	1.68	F4.1	-1.74	6293
6304	8.38	1.32	0.82	2.26	G4.6	+0.08	6304
6316	9.00	1.30	0.57	2.42	(F9)	-0.89	6316
6325	10.79	1.69	-	2.82	(G1)	-	6325
6333	7.75	0.96	0.30	1.75	F2.8	-1.71	6333
6341	6.50	0.63	0.02	1.10	F2.8	-1.99	6341
6342	10.10	1.36	-	1.95	(G2)	-	6342
6352	8.40	1.03	0.61	-	(G2)	-0.11	6352
6355	9.76	1.58	-	2.36	(G4)	-	6355
6356	8.28	1.14	0.58	1.85	G3.4	-0.21	6356
rz 2	-	-	-	-	-	-	Trz 2
6362	8.23	0.90	0.29	-	(F9)	-1.08	6362
6366	10.09	1.60	0.99	-	(G5)	+0.1:	6366
rz 4	-	-	-	-	-	-	Trz 4
P 1	-	2.0:	-	-	(G5):	-	HP 1
6380	-	-	-	-	-	-	6380
6388	6.64	1.16	0.62	-	G2.5	-0.10	6388
rz 1	-	-	-	-	-	-	Trz 1
on 2	-	-	-	-	-	-	Ton 2
6397	5.90	0.76	0.15	-	F4.8	-1.48	6397
6401	9.44	1.32	-	2.52	(F4)	-	6401
6402	7.49	1.26	0.60	2.10	F8.1	-1.14	6402
ol 6	13.6:	3.4:	-	-	-	-	Pol 6
6426	11.48	0.99	0.32	1.66	(F6)	-1.57	6426
rz 5	13.5	4.0	-	5.9	(G6)	-	Trz 5
6440	9.39	1.97	0.97	3.23	G4.6	-0.24	6440
6441	7.24	1.25	0.79	2.16	G2.6	-0.02	6441
rz 6	-	-	-	-	-	-	Trz 6
6453	9.77	1.17	-	2.53	(F2)	-	6453
6496	8.8	1.1:	-	-	-	-	6496
rz 9	-	-	-	-	-	-	Trz 9
6517	10.29	1.81	0.99	3.04	(G2)	-0.5:	6517
6522	8.75	1.20	0.64	1.95	F8.7	-0.06	6522

TABLE F (CONTINUED)

Cluster	E(B–V)	Mod_0^V	r kps	lg d	D ps	M_0^V	Cluster
6171	0.35	13.60	5.2	1.00	15	−6.48	6171
6205	0.02	14.00	6.3	1.22	30	−8.20	6205
6218	0.18	13.63	5.3	1.16	22	−7.29	6218
6229	0.06	16.67	21.6	0.65	28	−7.47	6229
6235	0.24	15.6	13	0.70	19	−6.1	6235
6254	0.26	13.19	4.3	1.18	19	−7.34	6254
6256	–	–	–	–	–	–	6256
Pal 15	–	–	–	–	–	–	Pal 15
6266	0.42	14.18	6.9	1.15	28	−8.91	6266
6273	0.36	14.0	6.3	1.13	25	−8.3	6273
6284	0.29	15.35	11.8	0.75	19	−7.2	6284
6287	0.52	14.5	7.9	0.71	12	−6.6	6287
6293	0.35	14.86	9.4	0.90	22	−7.5	6293
6304	0.50	14.0	6.3	0.83	12	−7.1	6304
6316	0.60	15.0	10.0	0.69	14	−7.8	6316
6325	0.92	14.7	8.7	0.63	11	−6.7	6325
6333	0.39	14.40	7.6	0.97	21	−7.82	6333
6341	0.03	14.34	7.4	1.05	24	−7.93	6341
6342	0.50	16.8	23	0.47	20	−8.2	6342
6352	0.34	12.88	3.8	0.85	8	−5.50	6352
6355	0.70	14.3	7	0.70	11	−6.7	6355
6356	0.32	15.41	12.1	0.86	25	−8.9	6356
Trz 2	1.2:	–	–	0.17	–	–	Trz 2
6362	0.15	13.69	5.5	1.03	17	−5.91	6362
6366	0.68	12.7	3.5	0.92	8	−4.6	6366
Trz 4	1.9:	–	–	0.00	–	–	Trz 6
HP 1	1.2	–	–	0.46	–	–	HP 1
6380	0.7:	–	–	0.59	–	–	6380
6388	0.36	13.8	6	0.94	15	−8.2	6388
Trz 1	2.4:	–	–	0.44	–	–	Trz 1
Ton 2	0.65:	–	–	0.53	–	–	Ton 2
6397	0.15	11.45	2.0	1.41	15	−6.0	6397
6401	0.74	14.1	7	0.75	11	−6.9	6401
6402	0.50	14.93	9.7	1.07	33	−8.94	6402
Pal 6	2.7:	13.3:	5:	0.86	10:	−5.7:	Pal 6
6426	0.30	16.2	17	0.50	16	−5.6	6426
Trz 5	3.1	14:	6:	0.32:	47	−9.5:	Trz 5
6440	1.14	13.7:	5.5:	0.73	9:	−7.6	6440
6441	0.46	14.6	8	0.89	19	−8.8	6441
Trz 6	1.1:	–	–	0.07	–	–	Trz 6
6453	0.66	15.9	15	0.54	25	−8.2	6453
6496	0.4:	13.2:	4:	0.84	9:	−5.8:	6496
Trz 9	–	–	–	–	–	–	Trz 9
6517	1.00	15.2	11	0.63	14	−7.9	6517
6522	0.47	13.81	5.8	0.75	10	−6.47	6522

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TABLE F (CONTINUED)

Cluster	V	B–V	U–B	V–I	Sp	[m/H]	Cluster
6528	9.67	1.43	0.95	2.28	G3.4	+0.06	6528
6535	10.62	0.96	0.34	–	(F6)	–0.7::	6535
6539	9.62	1.91	1.16	2.39	(G3)	+0.1::	6539
6541	6.91	0.76	0.14	–	F5.4	–1.61	6541
6544	8.30	1.46	0.68	2.50	F8.8	–0.94	6544
6553	8.13	1.63	1.06	2.89	G3.2	–0.22	6553
6558	–	–	–	–	–	–	6559
IC 1276	–	–	–	–	–	–	IC 1276
Trz 11	–	–	–	–	–	–	Trz 11
6569	8.76	1.29	0.54	2.12	(G0)	–0.81	6569
6584	8.87	0.79	0.17	–	G0.2	–1.00	6584
6624	8.31	1.10	0.57	1.84	G2.5	–0.24	6624
6626	6.99	1.09	0.45	1.82	F8.5	–0.90	6626
6637	7.79	1.02	0.48	1.68	G4.8	–0.18	6637
6638	9.03	1.12	0.54	1.92	G0.7	–0.65	6638
6642	8.8	1.12	0.47	1.86	F9.2	–0.82	6642
6652	8.93	0.89	0.36	1.44	G1.3	–0.68	6652
6656	5.07	1.00	0.28	1.83	F4.8	–1.68	6656
Pal 8	–	–	–	–	–	–	Pal 8
6681	8.18	0.72	0.14	1.31	F7.7	–1.34	6681
6712	8.13	1.14	0.53	2.00	G0.3	–0.83	6712
6715	7.61	0.84	0.24	1.44	F7.9	–1.17	6715
6717	–	–	–	–	–	–	6717
6723	7.26	0.74	0.26	1.36	F9.8	–0.79	6723
6749	11.07	1.63	–	–	(F8)	–	6749
6752	5.76	0.66	0.08	–	F5.6	–1.52	6752
6760	9.08	1.68	0.8:	2.80	(G0)	–0.76	6760
Trz 7	–	–	–	–	–	–	Trz 7
6779	8.21	0.87	0.21	1.48	F4.6	–1.77	6779
Pal 10	–	–	–	–	–	–	Pal 10
1925–30	–	–	–	–	–	–	1925–30
6809	6.33	0.69	0.12	1.27	F4.7	–1.55	6809
Pal 11	–	–	–	–	–	–	Pal 11
6838	8.28	1.12	0.53	1.81	G2.1	–0.36	6838
6864	8.52	0.86	0.28	1.52	F8.2	–1.18	6864
6934	9.03	0.77	0.20	1.24	F5.9	–1.46	6934
6981	9.35	0.74	0.11	1.28	F7.5	–1.38	6981
7006	10.67	0.74	0.15	1.22	F4.9	–1.50	7006
7078	6.48	0.68	0.06	1.18	F3.2	–2.02	7078
7089	6.50	0.68	0.08	1.17	F4.0	–1.72	7089
7099	7.56	0.60	0.04	1.10	F2.8	–1.78	7099
Pal 12	–	–	–	–	–	–	Pal 12
Pal 13	14.5	0.7:	–	–	(F6)	–1.25::	Pal 13
7492	11.48	0.40	0.22	–	(F5)	–1.2:	7492

TABLE F (CONTINUED)

Cluster	E(B–V)	Mod_0^V	r kps	lg d	D ps	M_0^V	Cluster
6528	0.66	13.93	6.1	0.57	7:	–6.24	6528
6535	0.33	14.7	8.7	0.56	9:	–5.1	6535
6539	1.06	12.8	3.6	0.84	7:	–6.3:	6539
6541	0.17	13.81	5.8	1.12	22	–7.4	6541
6544	0.72	12.9	3.8	0.95	10:	–6.8	6544
6553	0.82	12.6	3.3	0.91	8:	–7.0	6553
6558	0.4:	–	–	0.57	–	–	6558
IC 1276	0.7:	15.9:	15:	0.85	30:	–	IC 1276
Trz 11	–	–	–	–	–	–	Trz 11
6569	0.52	14.2:	7:	0.76	12:	–7.0	6569
6584	0.08	15.4	12	0.80	28	–6.8	6584
6624	0.30	15.2	11	0.77	19	–7.9	6624
6626	0.38	13.82	5.8	1.05	19	–7.97	6626
6637	0.18	13.99	6.3	0.85	13	–6.74	6637
6638	0.37	15.6	13	0.70	19	–7.7	6638
6642	0.38	15.0	10	0.65	13	–7.3	6642
6652	0.13	16.2	17	0.55	18	–7.6	6652
6656	0.38	12.19	2.7	1.38	19	–8.26	6656
Pal 8	0.6:	–	–	0.67	–	–	Pal 8
6681	0.04	15.6	13	0.89	30	–7.6	6681
6712	0.44	13.77	5.7	0.86	12	–6.95	6712
6715	0.15	15.75	14.1	0.96	38	–8.59	6715
6717	0.4:	–	–	0.59	–	–	6717
6723	0.03	14.54	8.1	1.04	26	–7.37	6723
6749	0.92	13.5:	5:	0.80	9:	–5.2	6749
6752	0.04	12.99	4.0	1.31	24	–7.35	6752
6760	0.92	13.2:	4.4:	0.82	8:	–6.9	6760
Trz 7	–	–	–	–	–	–	Trz 7
6779	0.21	14.74	8.9	0.85	18	–7.16	6779
Pal 10	0.8:	–	–	0.54	–	–	Pal 10
1925–30	0.18	–	–	0.57	–	–	1925–30
6809	0.08	13.3	4.6	1.28	25	–7.25	6809
Pal 11	0.24	–	–	0.50	–	–	Pal 11
6838	0.32	12.43	3.1	0.86	6	–5.11	6838
6864	0.17	16.5	20	0.78	35	–8.5	6864
6934	0.17	15.52	12.8	0.77	22	–7.00	6934
6981	0.06	15.94	15.4	0.77	26	–6.77	6981
7006	0.08	17.67	34.2	0.45	28	–7.24	7006
7078	0.09	14.95	9.8	1.09	35	–8.74	7078
7089	0.06	15.25	11.2	1.11	42	–8.93	7089
7099	0.06	14.34	7.4	1.04	24	–6.96	7099
Pal 12	0.07	–	–	0.46	–	–	Pal 12
Pal 13	0.02	16.6:	21:	0.25	11:	–2.2:	Pal 13
7492	0.02	16.12	16.8	0.79	30	–4.70	7492

Cluster	x	y	z	RV	Wt
104	+ 1.6	− 2.2	− 2.7	− 18	6.6
288	− 0.1	0.0	− 7.3	− 47	2.0
362	+ 2.8	− 4.6	− 5.6	+221	2.2
1261	+ 0.1	− 7.7	− 9.9	+ 46	0.8
Pal 1	−28:	+33:	+15:	−	−
Pal 2	−26:	+ 4:	− 4:	−	−
1851	− 3.3	+ 7.0	− 5.4	+310	2.3
1904	− 6.1	− 6.6	− 5.1	+198	2.1
2298	− 4.0	− 8.9	− 2.8	+ 64	0.5
2419	−55.0	− 0.4	+25.9	+ 1	0.7
2808	+ 1.9	− 8.7	− 1.8	+101	2.4
Pal 3	−28	−48	+50	−	−
3201	+ 0.5	− 4.2	+ 0.6	+493	3.2
Pal 4	−20	− 8	+64	−	−
4147	− 1.2	− 3.9	+17.8	+188	0.6
4372	+ 2.2	− 3.7	− 0.7	+ 66	1.2
4590	+ 4.0	− 7.0	+ 5.9	−116	0.4
4833	+ 2.8	− 4.2	− 0.7	+204	1.2
5024	+ 2.6	− 1.4	+16.4	−112	0.9
5053	+ 2.3	− 1.0	+12.9	−	−
5139	+ 3.0	− 3.7	+ 1.3	+230	2.1
5272	+ 1.3	+ 1.2	+ 8.7	−154	5.5
5286	+ 6.0	− 6.7	+ 1.7	+ 45	1.7
5466	+ 3.0	+ 2.7	+13.7	−	−
5634	+11.9	− 3.8	+14.5	− 63	0.4
5694	+24	−13	+16	−187	0.4
IC4499	+ 5:	− 6:	− 3:	−	−
5824	+17.7	− 9.2	+ 8.1	− 58	0.4
Pal 5	+10.5	+ 0.2	+10.8	−	−
5897	+ 9.0	− 2.8	+ 5.5	−	−
5904	+ 4.6	+ 0.3	+ 4.9	+ 50	4.2
5927	+ 5.3	− 3.5	+ 0.5	− 88	0.6
5946	+ 6.9	− 4.4	+ 0.6	−	−
5986	+ 7.7	− 3.3	− 2.0	+ 2	0.4
1608+15	+50±	+30±	+50±	−	−
6093	+ 9.0	− 1.2	+ 3.2	+ 19	0.8
6101	+ 4:	− 4:	− 2:	−	−
6121	+ 1.9	− 0.3	+ 0.6	+ 66	2.4
6139	+ 9.1	− 2.9	+ 1.2	+ 20	0.8
6144	+ 7.1	− 1.0	+ 2.0	−	−
6171	+ 4.8	+ 0.3	+ 2.1	−147	0.4
6205	+ 2.5	+ 4.1	+ 4.1	−240	3.9
6218	+ 4.6	+ 1.3	+ 2.4	− 16	1.1
6229	+ 5.2	+15.8	+13.9	−152	0.8
6235	+13	− 0.2	+ 3	−	−
6254	+ 3.8	+ 1.0	+ 1.7	+ 69	1.8
6266	+ 6.8	− 0.8	+ 0.9	− 77	1.1
6273	+ 6.3	− 0.3	+ 1.0	+114	0.9
6284	+11.6	− 0.3	+ 2.0	+ 22	0.4
6287	+ 7.6	0.0	+ 1.5	−	−
6293	+ 9.3	− 0.4	+ 1.3	− 73	4
6304	+ 6.3	− 0.5	+ 0.6	− 98	0.5
6316	+ 9.8	− 0.5	+ 1.0	−	−
6325	+ 8.7	+ 0.1	+ 1.2	−	−
6333	+ 7.4	+ 0.7	+ 1.4	+224	0.6
6341	+ 2.2	+ 5.6	+ 4.2	+118	3.3
6342	+22	+ 2	+ 4	−	−
6352	+ 3.5	− 1.2	− 0.5	−	−
6355	+ 7	− 0.1	+ 1	−	−
6356	+11.8	+ 1.4	+ 2.1	+ 32	0.6
6362	+ 4.3	− 2.9	− 1.6	− 18	2.4
6366	+ 3.1	+ 1.0	+ 1.0	−	−

APPENDIX (CONTINUED)

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Cluster	x	y	z	RV	Wt
6388	+ 5.5	− 1.4	− 0.7	+ 81	2.4
6397	+ 1.8	− 0.7	− 0.4	+ 11	4.0
6401	+ 6.4	+ 0.4	+ 0.4	−	−
6402	+ 8.7	+ 3.4	+ 2.5	−116	1.0
Pal 6	+ 5:	+ 0.2:	+ 0.1:	−	−
6426	+14.6	+ 7.8	+ 4.8	−	−
Trz 5	+ 6:	+ 0.1:	+ 0.0:	−	−
6440	+ 5.4	+ 0.7	+ 0.3	−118	0.7
6441	+ 8.3	− 0.9	− 0.7	− 70	0.4
6453	+15	− 1	− 1	−	−
6496	+ 4:	− 1:	− 1:	−	−
6517	+10	+ 4	+ 1	−	−
6522	+ 5.8	+ 0.1	− 0.4	− 24	0.1
6528	+ 6.1	+ 0.1	− 0.4	+114	0.3
6535	+ 7.6	+ 3.9	+ 1.6	−	−
6539	+ 3.4	+ 1.3	+ 0.4	−	−
6541	+ 5.6	− 1.0	− 1.1	−148	1.8
6544	+ 3.8	+ 0.4	− 0.1	− 12	0.4
6553	+ 3.3	+ 0.3	− 0.2	− 27	0.3
IC 1276	+14	+ 6	+ 1.5	−	−
6569	+ 7:	0:	− 1:	−	−
6584	+11.2	− 3.6	− 3.5	+160	0.4
6624	+11	+ 0.5	+ 1.6	+ 69	0.4
6626	+ 5.7	+ 0.8	− 0.6	0	0.7
6637	+ 6.2	+ 0.2	− 1.1	+ 74	1.0
6638	+13.0	+ 1.8	− 1.7	− 14	0.5
6642	+10:	+ 2:	− 1:	− 84	0.2
6652	+16.8	+ 0.4	− 3.4	−124	0.4
6656	+ 2.7	+ 0.5	− 0.4	−144	3.3
Pal 8	+15±	+ 4±	− 2±	−	−
6681	+12.9	+ 0.6	− 2.9	+198	0.4
6712	+ 5.1	+ 2.4	− 0.4	−124	0.7
6715	+13.6	+ 1.3	− 3.4	+122	1.8
6717	+10:	+ 2:	− 2:	−	−
6723	+ 7.7	0.0	− 2.4	− 3	0.4
6749	+ 4:	+ 3:	− 0.2:	−	−
6752	+ 3.3	− 1.4	− 1.7	− 39	4.0
6760	+ 3.5	+ 2.5	− 0.3	−	−
6779	+ 4.0	+ 7.8	+ 1.3	−145	1.9
Pal 10	+10±	+13±	+ 1±	−	−
6809	+ 4.2	+ 0.7	− 1.8	+169	2.1
Pal 11	+13:	+ 8:	− 4:	−	−
6838	+ 1.7	+ 2.5	− 0.2	− 80	4
6864	+17	+ 6	− 9	−198	2.0
6934	+ 7.4	+ 9.5	− 4.1	−360	0.6
6981	+10.6	+ 7.5	− 8.3	−255	0.5
7006	+14.2	+28.9	−11.3	−362	0.7
7078	+ 3.7	+ 7.9	− 4.5	−109	2.8
7089	+ 5.4	+ 7.3	− 6.6	− 5	3.9
7099	+ 4.5	+ 2.3	− 5.4	−175	1.8
Pal 12	+12:	+ 7:	−15:	−	−
Pal 13	+ 0.8	+15.6	−14.4	−	−
7492	+ 4.5	+ 6.0	−15.0	−	−

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SUPPLEMENTARY INFORMATION ON GLOBULAR CLUSTER IC 4499

After the book was ready for publication, the work of C. R. Fourcade and J. R. Laborde, the Globular Cluster IC 4499, Cordoba Astronomical Observatory Preprint, October 1973, was received. Globular cluster IC 4499 is of particular interest, because it may possibly have the greatest number of variable stars of the RR Lyrae type. Unfortunately, all of the cluster characteristics are very unreliable. Many of these characteristics can now be given with greater accuracy. All of the new data are given below. The weights are given in parentheses.

Table 3. $\Delta V = 2.8$ (1); $S = 4.3$ (1); $(B-V)_{0,0} = 0.78$ (1); $HB = 17.71$ (1)
Table 4. $K = 0.50$ (1)
Table 8. $M_V^{RR} = 0.80$ (1)
Table 9. $m_B^{RR} = 18.11$ (0.4)
Table 10. $V5 = 14.43$; $V25 = 15.10$; $B5 = 16.24$; $B25 = 16.58$
Table 11. $IR = 0.30$ (3.2)
Table C. $E(B-V) = 0.27$ (3)
Table D. $Sp = (F6)$ (1); $[m/H] = -1.36$ (5)
Table E. $Mod_{app}^V = 16.22$ (1.23)
Table F. $Mod_0^V = 15.41$; $r = 12.1$; $\lg D = 1.43$; $M_0^V = -5.5$
Appendix. $x = 6.9$; $y = -9.0$; $z = -4.2$

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